Age Estimation in Forensic Odontology: A Review

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ABSTRACT

Age is one of the essential factors, which play an important role in every aspect of life. Person recognition is an important feature of forensic medicine and dentistry. Age, gender, race, and so on is used for identification of a person. Chronological age, as recorded by registration of birth date, is used throughout an individual's life. Age estimation is of wider importance in Forensic medicine, not only for the purpose of identifying deceased victims, but also in connection with crime and accidents. Methods of age estimation in forensic odontology generally use dentition and craniofacial skeleton. The stages of development of teeth are among the most reliable tools in the process of identification of age, especially in the first and second decades. Later it depends on certain physical, chemical and biological changes, which affect the teeth and the craniofacial skeleton. The present article provides an overview of the most commonly used dental age estimation techniques in children and in adults described in the literature of Forensic dentistry like Teeth calcification, Demirjian's formula, Gustafson's method, Kvaal's method.

1. Introduction

Many anthropologists have studied the age systems, where age is often a major organizing principle. Age systems include formal age classes of individuals of similar numerical age, age grades or developmental stages based on social and biological development, and relative ages of individuals. Body development is not completely associated with biological and chronological age. In many cases, chronological age and biological age may not be the same, due to the developmental variations. Hence, different parameters such as dental age, bone age, mental age, and other factors such as menarche, voice change, height, and weight are considered as proxy indicator for biological age and body development. The term physiologic age is a measure for describing the growth status of an individual child, whereas chronologic age conveys only a rough approximation of this status because of the range in development observed for any given age.[1] The chronological age is the age measured by the calendar; the skeletal age is determined by reference to stages of skeletal development known to occur at particular times in the average individual. Dental development is more reliable as an indicator of biological maturity in children. Dental maturity is more relevant as it is less affected by nutritional and endocrine status. The dental age is determined by reference to the ever-growing volume of statistical information concerning each stage of development of the human deciduous and permanent dentitions and the changes in the latter which result from its use throughout life.[2] This paper reviews different dental age estimation methods that are used- Morphological method, biochemical method, and radiological method.

2. Understanding Dental Age:

The terms chronologic age and dental age are synchronous in the normal patient, in early or late developers a difference of ±2 years from the average value is seen.[3] The chronological age and developmental stages of deciduous and permanent teeth have been well documented by Wheeler.[4] Later, Krogman illustrated how the aging process is reflected in the bones and teeth from birth to old age (80 years); thus linking the timing of general growth with that of the dentition.[5]

The somatic development is generally related to chronological age and, as a result, measurements of somatic maturity, for example bone age, menarche and height, have been used to estimate chronological age in the absence of accurate age data.[6] Gleiser and Hunt (1955) first stated that 'the calcification of a tooth may be more meaningful indication of somatic maturation than is its clinical emergence'.[7] Clinical emergence is often erroneously called eruption, and may be influenced by local factors as Ankylosis, early or delayed extraction of the deciduous teeth, impaction and crowding of the permanent teeth. The formation of the permanent teeth is not affected by these local factors. If clinical emergence is used as the criterion for dental age assessment, it could be applied only up to the age of 30 months and after the age of 6 years.

In general teeth are used corroboratively rather than diagnostically for the determination of age, sex, and race. For age, there are two sequential developmental factors: calcification and eruption.[5] Krogman in 1968 stated that "Radiography was the one ray of hope for standardization of tooth formation i.e. its calcification and eruption".[8] Reports by western workers served to be the stepping stones in the ultimate and complete understanding of the phenomenon of growth and maturation of the dental system.

The earliest documented reports related to the calcification status of formative stages of permanent teeth of Indian children are those by Powell A (1902).[9] He attempted to define the range of variation in the development of teeth so as to ascertain the chronologic age, in a case of rape. In 1956, Demisch and Wartmann[10] reported on 81 males and 70 females from Boston, studied over an 8-16 year period. A seven stage calcification schedule was used to study the mandibular third molar (M_3) alongside hand-wrist x-rays for skeletal age. At about the same time Garn SM, Lewis AB and Shoemaker DW[11] presented new data on the sequence of calcification of the mandibular premolar (P_1, P_2) and molar teeth (M_1, M_2), in contemporary American white children. Their findings reported that M_1, P_1 and M_3 invariably showed initial calcification first, second and last respectively. P_2 and M_2 calcification varied in the order of appearance and often calcified at the same time.

In 1958, Garn S.M., Lewis A.B., Koski and Polacheck D[12] reported on the sex differences in tooth calcification, eruption and osseous development. They found the girls to be approximately 3% ahead of the boys in tooth calcification, 5% ahead in tooth eruption and 10% - 25% ahead in osseous development. Nolla (1960)[13] proposed a system of 10 stages of calcification for all permanent teeth moving from stage 1 (no sign of calcification) to stage 10 (apical end completed), besides a 0 stage which points out the absence of dental germs. In 1962, Gron Anna Marie[14] reported that majority of teeth had at least three fourth of root length at the time of clinical appearance. He concluded that tooth emergence appeared to be more closely related with the stage of root formation than with the chronological or skeletal age of the child. Two of the most thorough studies of tooth formation stages are those by Moorrees C. F. A., Fanning E .A. and Hunt E. E.(Jr) (1963),[1] for lower Canine, lower M_1 and lower M_2 and by the same authors for lower I_{1-2}, lower C, P_1, P_2, M_1, M_2 and M_3. The study offered two interesting conceptual definitions:

- Physiological age is estimated by the maturation of one or more tissue systems expressed in terms of the specific tissue studied.
- Maturation is scaled by the occurrence of one or the sequence of multiple events that are irreversible.

Nanda R.S. and Chawla T.N. (1966)[15] studied Intra-oral periapical full mouth radiographs of school children in Lucknow to determine the level of development of each of the permanent teeth. They reported that at nearly all age levels, root formation of Indian children was always lesser and slower than that of American children; perhaps related to the difference in the nutritional status of Indian children. Noble in 1974 published a comprehensive review on the estimation of age from dentition, right from Gleiser and Hunt 1955 (a combination of radiographical and histological techniques), Krauss and Jordan 1965 (the commencement of mineralization), to Calonius et al 1970 (examination of histological preparations of fetal and perinatal specimens).[2]

3. Age Estimation Methods:

Dental age estimation uses morphologic, radiographic, histologic and biological methods and could be classified as follows: [16]

1. Visual or clinical / morphological method
   a. Clinical eruption of deciduous and permanent teeth in oral cavity.
   b. Foti B et al multiple regression equations.
   c. Kvaal et al method
2. Radiographic method
   a. Changes in the orientation of mental foramen and inferior alveolar canal
   b. Eruption and formation of mandibular third molar
   c. Trabecular pattern in jaws
   d. Pulp/tooth area ratio of teeth
   e. Pattern of lamina dura
   f. Eruption sequence
   g. Schour and Massler chart (20 stages of dental development from 4 months to 21 years)
   h. Demirjian's method using dental maturation chart
   i. Nolla's calcification stages
3. Histological and Biochemical methods
   a. Gustafson's technique
   b. Incremental lines of Retzius
   c. Prenatal and postnatal line formation
   d. Racemization of collagen in dentin
   e. Cemental incremental lines
   f. Translucency of dentin

4. Estimation of Age in Children and Adolescents:

Radiographic Methods:

Demirjian and coworkers (1973)[17] developed a method of age estimation which over the years has become the most widely used technique to assess age from the dentition of children and adolescents. Initially the method was consisting of seven teeth (central incisor till 2nd molar) and 8 stages (A to H). In 2004, Chaillet and Demirjian incorporated third molar allowing its application to just over 18 years of age i.e. the age with legal implication.[18] For greater accuracy, the authors included the stage 0 (no calcification) and the stage 1 (initial calcification). Thus for each Orthopantomogram there were ten stages from 0 to 9 for each tooth. The authors concluded that Demirjian's 7-teeth method had a high accuracy (± 1.2 years) but poor reliability, by adding the third molar, the authors had increased the possibility of prediction until 18 years of age and the 8-teeth method offered greater reliability. Each tooth was rated according to the developmental stage and was given a numerical scoring (Table 1, 2). These eight maturity scores were then added to get a 'total maturity score' (S), which was substituted in the following regression formulas to get the chronological age of each subject.

$$\text{Age (Males)} = (0.0000615 \times S^3) - (0.0106 \times S^2) + (0.6997 \times S) - 9.3178$$

Age (Females) = $(0.000055 \times S^3) - (0.0095 \times S^2) + (0.6479 \times S) - 8.4583$

The Demirjian's method has certain shortcomings as,

1) In case of missing tooth the formula cannot be applied, unless the tooth is present on the other side.
2) Various developmental stages of the tooth may not be expressed in the given ten developmental stages.
3) The appreciation of developmental stage may become difficult as the choice of the tooth developmental stage is quite subjective.
4) Maturity scores are not given for stage 1 to stage 4 in case of 1st molar, central and lateral incisor; thus excluding the individuals below the age of 4 to 4.5 years.

The studies by Demirjian et al were based on data derived from panoramic x-rays of 4756 French-Canadians children. However, several studies have shown that results are less accurate if another population is compared to Demirjian's standards and highlight the necessity to create databases representative for each population. In this scenario, Koshy.S and Tandon.S (1998)[19] compiled a new maturity score for South Indian Population thus providing a significant contribution towards data on dental age assessment from India. Chaillet N. et al (2004)[20] came up with population specific score and the cubic equations for the Belgian children aged between 2 to 16 years. The same authors Chaillet N et al in 2004,[21] derived dental maturity curves for Finnish children using Dental Panoramic radiographs. In the following year (2005) Chaillet N et al[22] compared the dental maturity in children of different ethnic origins. The aim was to give dental maturity standards when the ethnic origin was unknown and to compare the efficiency and applicability of this method to forensic sciences and dental clinicians. Multi-ethnic timing analysis of dental maturity showed three major groups: Australia (with the fastest dental maturity), France and Finland were the first, Belgium and Sweden were the second; and French-Canadians and Koreans had the lowest dental maturity.

Acharya AB (2011)[23] developed an Indian-specific regression formula, by applying the Demirjian's formula on an Indian sample and compared the age prediction success to that in the original study.

Age (Males) = $27.4351 - (0.0097 \times S^2) + (0.000089 \times S^3)$

Age (females) = $23.7288 - (0.0088 \times S^2) + (0.000085 \times S^3)$

The sample consisted of Orthopantomograph of 547 Indians (348 females, 199 males) aged 7–25 years. Demirjian's formulas resulted in inferior age prediction in Indians (9.2% misclassification at 99% confidence interval vs. 0% misclassification in the original study); therefore, India-specific regression formulas were developed, which gave better age estimates (mean absolute error, MAE = 0.87 years) than the original formulas (MAE = 1.29 years). Thus it was concluded that Demirjian's 8-teeth method also needs adaptation prior to use in diverse populations. In 2011, Kumar VJ and Gopal KS[24] compared the reliability of age estimation using Demirjian's 8 teeth method following the French maturity scores and Indian specific formula. They reported that the age estimation using Indian specific formula narrowed down the error rate to just over one year thus making this method reliable.

In 1994, Staaf V et al[25] tested whether metric measurements of crown height, apex width, and root length during tooth development could be a better basis for correlation with age than the classical methods based on subjective estimations of various stages of tooth development. The study was based on panoramic radiographs of 541 children from an area of homogenous population. The parameters measured were the crown height, length of distal and mesial roots in molars, length of single rooted teeth, width of apex at distal and mesial root apices, width of apex of single-rooted teeth. The variables were introduced into a multiple regression model by a stepwise procedure. A comparison between the real age and the age estimated from the mathematic models for the whole material showed a mean difference of 0.12 day (S.D = 326 days) for boys and 0.44 days (S.D = 290 days) for girls. They also pointed out that the normal differences between true and estimated age indicated that most of the variability in their study was caused by individual variation and not systematic error.

In 2002 Mesotten K et al[26] obtained the multiple regression formulae to estimate age from dental developmental stages of third molars evaluated on Orthopantomogram. But these formulae were applicable only when all four third molars were present. The investigation revealed that the chronological age of a Caucasian individual may be estimated based on regression formulas with a S.D of 1.52 or 1.56 years for males and females respectively.

Radiographic and Clinical Methods:

Unlike most other literature on dental age estimation, Foti B et al in 2003,[27] provided mathematical models for age calculation based on counting erupted teeth, and if possible, germs, applicable both in clinical and radiological examinations. To improve the accuracy of the predicted age, a mathematical model was set up taking into account several variables in order to calculate the continuous variable, which is real age, i.e. they used a step-wise ascending multiple regression analysis. The age estimates calculated with the help of the regressive models proved to be reliable estimations of the real age, derived from the formulas using all variables (Model 1), all variables except those of tooth germs (Model 2), using all maxillary variables except those of the germs (Model 3) or using all mandibular variables except those of the germs (Model 4). The regressive model based on the utilization of all variables resulted in the narrowest confidence interval (± 3.5years). The authors proposed four regressive models providing 95% confidence interval age estimates in any situation, i.e. whether there were available panoramic radiographs or not, even if they had incomplete skeletal remains.

5. Age Estimation in Adults

Gustafson's Method[28]:

Age estimations in excess of twenty-five years were made, using Gustafson's method involving attrition, secondary dentine deposition etc. Gustafson G (1947) described the age changes occurring in the dental tissue as attrition of the enamel, sclerosis of the dentin, denticles in the pulp, deposition of cementum, alteration in the periodontal structures, continuous eruption of the teeth, root resorption and transparency of the root. He designed diagrams from the ground sections of adult human teeth. Each sign was allotted 0, 1, 2 and 3 points according to degree of development. An increase in points corresponded to increase in age. The point value of each age changes were added together and substituted in the equation as $y = 11.43 + 4.56\,x$, where y = age and x = points. The error of estimation as calculated by Gustafson was ±3.6 years.

But this method was criticized for a number of reasons:

a. Can be used only in postmortem cases as it requires extraction of tooth.
b. Time-consuming as too many age related changes are involved.
c. Attrition is not always age related.
d. Secondary dentin is to a great extent due to pathological influences on pulp cells.
e. Periodontitis is often impossible to determine due to decomposition of soft tissue.

Gustafson's technique was later improved by Dalitz[29] in 1962 and then by Johanson[30] in 1971. Dalitz suggested 5 point system i.e. 0-4 points; excluded two changes, root resorption and secondary dentin formation; and came up with a regression equation: $E\ (\text{age}) = 8.691 + 5.146A + 5.338P + 1.866S + 8.411T$. Johanson differentiated seven different stages and evaluated all the six original criteria. He studied the root transparency in detail and stated that it is clearer when the thickness of the ground section of the tooth was 0.25 mm. The formula inferred was: $\text{Age} = 11.02 + 5.14A + 2.3S + 4.14P + 3.71C + 5.57R + 8.98T$. Bang and Ramm (1970)[31] stated that the root dentin appears to become transparent during the third decade starting at the tip of the root and advancing coronally with age. Maples (1978)[32] suggested use of only two criteria i.e. secondary dentin formation and root transparency of the six Gustafson's criteria and reported new regression formula $\text{Age} = 13.45 + 4.26x$. Solheim (1993)[33] used five of the changes excluding root resorption and added three new age related changes, surface roughness, color and sex. In his study of 1000 teeth excluding molars, he found a good correlation between age and the whole number of changes.

Radiographic and Morphological Methods:

In 1994 Kvaal and Solheim[34] presented a method where radiological and morphological measurements were combined. Using radiographs the pulp length and width as well as root length and width from the radiographs were measured. The length of apical translucency and periodontal retraction were also included in certain teeth. Then different ratios between the root and pulp were measured. The results showed the strongest correlation with age to be in the ratio between the width of the pulp and root. Thus it indicates that the rate of deposition of dentine on the mesial and distal walls is more closely related to age than that on the roof of the pulp cavity. The method is non-destructive and can be applied in living individuals as well as postmortem cases.

Using Intra Oral Periapical Radiographs:

In 1995, Kvaal S.I et al[35] derived a method for age estimation of an adult from measurements of the size of the pulp on full mouth dental radiographs, without extraction and destruction of teeth. Their method used the tooth, root, and pulp size measurement of six teeth (mandibular lateral incisors, canines and first premolars and maxillary central and lateral incisors and second premolars) observed on periapical radiographs. The results indicated that the ratio between the length of tooth and root was weakly or not significantly correlated with age and was excluded from further statistical calculations. The correlation between age and mean ratios from several teeth was stronger than that from single teeth.

Using Orthopantomograph:

Karaarslan B et al (2010)[36] evaluated orthopantomographs (OPGs) of 238 turkish individuals of known age ranging from 1-60 years for presence of primary teeth; presence of mixed dentition and third molar teeth; apexogenesis and maturation stage of third molar teeth; enamel attrition; level of teeth; width of the rootcanal and pulp cavity; and, level of alveolar bone resorption. OPGs were evaluated by two independent dentists, and age estimation was achieved according to the decades. Among 238 OPGs, the first dentist predicted 174 of the cases (73.1%) correctly and 64 of cases (26.9%) incorrectly. The second dentist predicted 171 cases (71.8%) correctly and 67 cases (28.2%) incorrectly. The author concluded that the age estimation through evaluating OPGs was most accurate in the first decade and least accurate in the fourth decade.

Shendarkar AT et al[37] in their study of 32 municipal employees attempted to arrive at a fairly conclusive range of age with respect to changes in physical features, especially graying of hair, wrinkling of skin and radiological evaluations of fusion of components of the sternum and changes in the teeth and mandible. The changes in the mandible noted were, namely the perpendicular distance of the mental foramen from lower border of body of the mandible (D1), the least perpendicular distance of the mandibular canals from the tangents drawn along the lower borders of the body of the mandible (D2), and the angle between the tangents drawn along the posterior border of the rami of the mandible and the lower borders of the body of the mandible. Among the age changes in the mandible, the right and left angles (MRA & MLA) and the least perpendicular distance between the mandibular canal on the right side and a tangent drawn along the lower border of the body of the mandible (MRD2) turned out to be the most reliable parameters in the assessment of age in the later years.

Mohite DP et al (2011)[38] compared both radiographic and histologic methods of age estimation to determine their accuracy. Orthopantomographs (OPG) were taken of the 50 mandibles from cadavers (aged 20-69 years) and following parameters were measured: length of ramus (mm), height of body of mandible (mm), distance of lower border of mandible (LB) to inferior margin of mental foramen (IMF) (mm) (left and right), distance of inferior margin of mental foramen (IMF) to crest of alveolar bone (CAR) (mm) (left and right), gonial angle, antegonial (AG) angle, antegonial (AG) depth, width of the cortex at the body and at the antegonial region (TCB at AG). Ground sections from the region of the body of the mandible (premolar region) were made and in each section the number of osteons, diameter of the Haversian canal, average number of concentric lamellae per osteon, area of the Haversian canal (HC area), area of osteon (AR of OS) and Haversian canal perimeter (HC perimeter) were measured. Of the various parameters studied, they concluded that the histologic parameters recorded ages, which were closer to the actual age.

Using Craniofacial Skeleton:

The time of appearance of ossification centers, site, size and degree of fusion with other part of the bone can be used for age estimation upto 21 years. After 21 years the assessment of age is based on the changes in configuration, start of closure of sagittal/ coronal sutures (25 years); completion of sagittal suture closure (32-35 years) and coronal suture closure (40 years); Fusion of lambdoid suture (45 years); fusion of squamous portion of the temporal bone with parietal bone (60 years).[39] Manne et al have described a method of estimating age from the four maxillary sutures and concluded that it can be used to give an age range if not the exact age.[40]

Biochemical Methods:

The biochemical methods are based upon the racemization of amino acids, which is a reversible 1st order reaction and is relatively rapid in living tissues in which metabolism is slow. It has been reported that Aspartic acid has highest racemization rate of all amino acids and is normally stored during aging. L-aspartic acids are conversed to D-aspartic acids and thus the levels of D-aspartic acid in human enamel, dnetin and cementum increase with age. The D/L ratio has been shown to be highly correlated with age.[41] Alkass K et al (2010)[42] analyzed forty four teeth from forty one Swedish individuals using aspartic acid racemization analysis of tooth crown dentin, and radiocarbon analysis of enamel. Radiocarbon analysis showed an excellent precision with an overall absolute error of 1.0 ± 0.6 years. Aspartic acid racemization also showed a good precision with an overall absolute error of 5.4 ± 4.2 years. Radiocarbon analysis gives an estimated year of birth whereas aspartic acid racemization analysis indicates the chronological age of an individual at the time of death. The authors claimed that the combination of these methodologies can help the forensic people to determine the identity and time of death of unidentified individuals.

In yet another study, Buchholz BA, Spalding KL (2010)[43] isolated enamel from human teeth and processed to form graphite and carbon14 (^{14}C) levels which were measured using accelerator mass spectrometry. As there is no turnover of the enamel after it is formed, ^{14}C level in the enamel represents ^{14}C levels in the atmosphere at the time of its formation. Radiocarbon dating is typically an archeological tool rather than forensic one. For radiocarbon analysis of tooth age, the upper limit of the enamel formation is used, that is the time of enamel lay down completion which balances lag periods of ^{14}C incorporation from the atmosphere to the body. The technique reports accurate determination of age with precision ± 1.5 years. Birth information significantly helps investigators in identifying deceased individual.

6. Conclusion

The accuracy of the dental aging is not uniform among the different population and different methods. Research in forensic odontology is ongoing and different techniques and numerous studies are being published with either new methodology or newer formulae demonstrating various accuracy, precision and reliability. Traditional methods such as radiographic examination of dental and skeletal development to determine age are being replaced by microfocused computer tomography[44] and cone-beam CT scan-3D images,[45] in order to minimize the magnification error. As also sophisticated methods such as chemical analysis of tooth dentin by aspartic acid racemization and radiocarbon analysis are becoming more accessible. With so many options available more than one technique may be appropriate for a particular case. For this reason when investigating a case the Forensic odontologist should apply different techniques available and perform repetitive measurements and calculations in order to achieve a reliable conclusion.

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TABLES

TABLE 1- Individual maturity score assigned for each tooth as per their developmental stage for Boys.

Stage / Tooth	0	1	2	3	4	5	6	7	8	9
M3	6.19	7.64	8.28	8.86	9.89	11.17	12.25	13.66	14.07	15.32
M2	1.7	2.98	3.41	4.74	4.88	6.69	7.89	9.08	11.13	13.63
M1						2.13	3.73	4.94	7	11.22
PM2		1.69	2.2	3.41	3.41	5.59	6.96	8.68	10.64	13.11
PM1			1.7	1.98	3.52	5.19	6.47	8.18	9.84	12.57
C				1.7	2.67	4.34	6.47	7.59	9.52	12.56
I2						2.55	4.71	5.75	6.97	10.91
I1						2.31	4.35	5.16	6.56	10.68

TABLE 2- Individual maturity score assigned for each tooth as per their developmental stage for Girls.

Stage / Tooth	0	1	2	3	4	5	6	7	8	9
M3	6.4	7.74	8.92	9.31	10.22	11.04	12.65	13.77	14.45	16.65
M2		2.57		2.65	4.1	6.51	8	9.13	11	13.84
M1						2.58	3.25	4.25	6.88	10.94
PM2			2.43	3.43	3.83	5.75	6.81	8.7	10.8	12.79
PM1				2.56	3.54	5.09	6.31	8.09	9.82	12.29
C					2.55	3.15	5.4	7.19	9.22	11.99
I2						2.65	4.54	5.4	7.02	10.89
I1						2.58	3.1	5.02	6.66	10.61