Review Article

Dental Age Estimation Methods: 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 identification is an important aspect 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 referred throughout an individual's life. Age is an important factor in clinical practice; research and court of law. Major dental clues once neglected are increasingly used to solve the crime. Age is estimated on the basis of chronological age and bone age, dental age, mental age, and others. Dental age is considered to be vital as tooth development shows less variability than other developmental features and also low variability in relation to chronological age. Hence, dental age is considered to be vital in establishing the age of an individual. Different morphological stages of mineralization correlate with the different developmental stages. This paper reviews various aspects of age estimation like morphological, biochemical, and radiographical methods and its scope and limitation.

Keywords: Age estimation, Demirjian method, Dental age, Panoramic radiograph

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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.[1]

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.[2]

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.[2]

Dental maturity is considered better than the emergence of teeth into the oral cavity as it is scarcely influenced by local factors such as lack of space and systemic factors. It is also widely used to estimate the chronological age of children of unknown birth records.[3]

This paper reviews different dental age estimation methods that are used: Morphological method, biochemical method, and radiological method.

These methods have inherent advantages and disadvantages. Although there are many methods of age estimation Demirjian method has been used universally with appropriate modifications.

METHODS OF AGE ESTIMATION

The first known attempts that used teeth as an indicator of age originated from England. In the early 19th century, because of economic depression due to the industrial revolution, juvenile work and criminality were serious social problems. Edwin 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.[4]

Literature describes several techniques that address age estimation in adults. The various methods are divided into three categories:

1. Morphological methods
2. Biochemical methods
3. Radiological methods.

MORPHOLOGICAL METHODS[4]

Morphological methods are based on assessment of teeth (*ex-vivo*). Hence, these methods require extracted teeth for microscopic preparation. However, these methods may not be acceptable due to ethical, religious, cultural, or scientific reasons.

Gustafson (1950), Dalitz (1962), Bang and Ramm (1970), Johanson (1971), Maples (1978), Solheim (1993) are few morphological methods.

Gustafson's Method (1950)[4]

Gustafson (1950) and Thoma (1944) described the age changes occurring in the dental tissues and noted six changes related to age. They are:

a. Attrition of the incisal or occlusal surfaces due to mastication (A)
b. Periodontitis (P)
c. Secondary dentin (S)
d. Cementum apposition (C)
e. Root resorption (R)
f. Transparency of the root (T)

Gustafson suggested the last two changes. In the method proposed, each sign was ranked and allotted 0, 1, 2, 3 points. The point values of each age-change are added according to the following formula:

$A_n + P_n + S_n + C_n + R_n + T_n$ = points.

The exact equation calculated was: y = 11.43 + 4.56x, where, y = age and x = points according to the formula above. The error of estimation as calculated by Gustafson (1950) was ±3.6 years.

Disadvantage: Cannot be used in living person.

Dalitz Method (1962)[4]

Dalitz re-examined Gustafson's method and suggested a 5-point system from 0-4, instead of the 4-point system that was previously used. This change was proposed in order to give a slightly greater accuracy. The results showed that root resorption and secondary cementum formation could be disregarded. The other criteria, attrition (A), periodontitis (P), secondary dentine (S) deposition, and transparency of the root (T) of the 12 anterior teeth, are related appreciably to age and to a similar degree. Dalitz suggested this below formula.

E = 8.691 + 5.146A + 5.338P + 1.866S + 8.411T

Disadvantage: It does not take into account bicuspids and molar teeth.

Bang and Ramm Method (1970)[4]

They found that the root dentine appears to become transparent during the third decade starting at the tip of the root and advancing coronally with age.

It was found that, transparency of the root dentin advances coronally from the tip of the root during the third decade. A great advantage of the method is that good results are obtained by measuring intact roots only.

Johanson Method (1971)[4]

Age changes were differentiated into seven different stages (A_0-A_3) and evaluated for the same six criteria, mentioned earlier, attrition (A), secondary dentine formation (S), periodontal attachment loss (P), cement apposition (C), root resorption (R), and apical translucency (T). Johanson made a more detailed study of the root transparency and stated that it is more clear when the thickness of the ground section of the tooth was 0.25 mm. The following formula was recommended:

Age = 11.02 + (5.14 × A) + (2.3 × S) + (4.14 × P) + (3.71 × C) + (5.57 × R) + (8.98 × T)

Maples Method (1978)[4]

Suggested the use of only two criteria of the total six Gustafson recommended-(secondary dentine formation and root transparency), in order to make the method more simple and accurate.[3]

Solheim Method (1993)[4]

Solheim used five of the changes that Gustafson recommended (attrition, secondary dentin, periodontitis, cementum apposition, and root transparency) and added another three new changes that showed a significant correlation in different types of teeth. The three new age-related changes were surface roughness, color, and sex.

BIOCHEMICAL METHODS[4]

The biochemical methods are based on the racemization of amino acids. The racemization of amino acids is a reversible first-order reaction and is relatively rapid in living tissues in which metabolism are slow. Aspartic

acid has been reported to have the highest racemization rate of all amino acids and to be stored during aging. In particular, L-aspartic acids are converted to D-aspartic acids and thus the levels of D-aspartic acid in human enamel, dentine, and cementum increase with age.

Some of the methods are:
1. Helfman and Bada method (1975, 1976)[4]
2. Ritz *et al*. method (1995)[4]

Helfman and Bada Method (1975, 1976)

The authors reported studies that focused on the racemization of amino acids and obtained a significant correlation between age and ratio of D-/l-enantiomers in aspartic acid in enamel and coronal dentin.

Ritz *et al.* Method (1995)

Used the racemization method in dentinal biopsy specimens in order to estimate the age of living individuals. This method emerged from the need to identify the age of living individuals without extracting teeth.

RADIOGRAPHIC METHODS[5]

Radiology plays an indispensable role in the human age determination. Radiological images are utilized in the process of age estimation, which is one of the essential tools in identification in forensic science. Radiographic assessment of age is a simple, non-invasive and reproducible method that can be employed both on living and unknown dead.

Various radiographic images that can be used in age identification are intraoral periapical radiographs, lateral oblique radiographs, cephalometric radiographs, panoramic radiographs, digital imaging and advanced imaging technologies.

The radiological age determination is based on assessment of various features as follows:

- Jaw bones prenatally
- Appearance of tooth germs
- Earliest detectable trace of mineralization or beginning of mineralization
- Early mineralization in various deciduous teeth during intrauterine life
- Degree of crown completion
- Eruption of the crown into the oral cavity
- Degree of root completion of erupted or unerupted teeth.
- Degree of resorption of deciduous teeth
- Measurement of open apices in teeth
- Volume of pulp chamber and root canals/formation of physiological secondary dentine
- Tooth-to-pulp ratio
- Third molar development and topography

Age estimation is grouped into three phases:
1. Pre-natal, neonatal and post-natal
2. Children and adolescents
3. Adults

Pre-natal, Neonatal and Post-natal Age Estimation[5]

Radiographically, the mineralization of deciduous incisors starts at the 16th week of intrauterine life. Before the mineralization of tooth germs starts, the tooth germs may be visible as radiolucent areas on the radiograph; the subsequent radiographs of the mandible will depict the deciduous teeth in various stages of mineralization as per the pre-natal age of the fetus. One of the methods employed is:

Stages by Kraus and Jordan (1965)[5]

They studied the early mineralization in various deciduous teeth as well as the permanent first molar. The development is described in 10 stages, denoted by Roman numerals from I to X; the IXth stage includes three stages and the Xth stage includes five stages.

Age Estimation in Children and Adolescents[5]

Dental age estimation in children and adolescents is based on the time of emergence of the tooth in the oral cavity and the tooth calcification. The radiographic analysis of developing dentition, especially when there is no clinical evidence available (2.5-6 years) as well as the clinical tooth emergence in various phases will help in age determination.

Methods applied for age determination in children and adolescents

Schour and Masseler method (1941)[5]

In 1941, Schour and Masseler studied the development of deciduous and permanent teeth, describing 21 chronological steps from 4 months to 21 years of age and published the numerical development charts for them. These charts do not have separate surveys for males and females.

Nolla's method (1960)[5]

Nolla evaluated the mineralization of permanent dentition in 10 stages. After every tooth is assigned a reading, a total is made of the maxillary and mandibular teeth and then the total is compared with the table given by Nolla.

The advantages of this method are that it can be applied to an individual with or without the third molar and that girls and boys are dealt with separately.

Moorees, Fanning and Hunt method (1963)[5]

In this method, the dental development was studied in the 14 stages of mineralization for developing single and multirooted. Permanent teeth and the mean age for the corresponding stage was determined.

Age estimation using open apices (Cameriere method)[5]

Various studies assessed the relationship between the age and measurement of open apices in teeth. The seven left permanent mandibular teeth were valued. The number of teeth with root development completed with apical ends completely closed was calculated (N0). For the teeth with incomplete root development, that is, with open apices, the distance between inner sides of the open apex was measured (A). For the teeth with two roots, the sum of the distances between inner sides of 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 (s) and the numbers of teeth with root development complete (N0). The values are substituted in the following regression formula for age estimation.

Age = 8.971 + 0.375 g + 1.631 × 5 + 0.674 N0 – 1.034 s – 0.176 s N0

Where g is a variable equal to 1 for boys and 0 for girls.

Age Estimation in Adults[5]

Clinically, the development of permanent dentition completes with the eruption of the third molar at the age of 17-21 years, after which the radiographic age estimation becomes difficult. The two methods commonly followed are the assessment of the volume of teeth and the development of the third molar.

1. Volume assessment of teeth
   a. Pulp-to-tooth ratio method by Kvaal
   b. Coronal pulp cavity index
2. Development of third molar
   a. Harris and Nortje method
   b. Van Heerden system

Volume assessment of teeth[5]

The age estimation in adults can be achieved by radiological determination of the reduction in size of the pulp cavity resulting from a secondary dentine deposition, which is proportional to the age of the individual.

Pulp-to-tooth ratio method by Kvaal[5]

In this method, pulp-tooth ratio is calculated for six mandibular and maxillary teeth, such as maxillary central and lateral incisors; maxillary second premolars; mandibular lateral incisor; mandibular canine; and the first premolar. The age is derived by using these pulp to tooth ratios in the formula for age determination given by Kvaal *et al*.

Age = 129.8 – (316.4 × m) (6.8 × [W-L])

The Coronal Pulp Cavity Index[5]

This method calculates the correlation between the reduction of the coronal pulp cavity and the chronological age. Only mandibular premolars and molars were considered, as the mandibular teeth are more visible than the maxillary ones. Panoramic radiography is used to measure the length (mm) of the tooth crown (coronal length, [CL]) and the length (mm) of the coronal pulp cavity (coronal pulp cavity height or length [CPCH]). The tooth-coronal index (TCI) is computed for each tooth and regressed on the real age of the sample using the formula.

$$TCI = \frac{CPCH * 100}{CL}$$

Development of third molar[6]

The radiographic age estimation becomes problematic after 17 years of age as eruption of permanent dentition completes by that age with the eruption of the third molar. Later, the development of the third molar may be taken as a guide to determine the age of the individual.

Harris and Nortje method[5]

They have given five stages of third molar root development with corresponding mean ages and mean length.

van Heerden system[5]

The development of the mesial root of the third molar was assessed to determine the age using panoramic radiograph (in this system he considered five stages).

DEMIRJIAN, GOLDSTEIN, AND TANNER METHOD (1973)[6]

In 1973, Demirjian introduced a method (DemI973) which estimated chronological age based on developments of seven teeth from the left side of the mandible. This method was similar to that of Tanner, Whitehouse, and Healy, who estimated chronological age based on the maturity of hands and wrists.

Demirjian, Goldstein, and Tanner used the stages have usually been marked by recognizable tooth shapes, from the beginning of calcification through to final mature form. Useful stages must be easily recognizable, and

such that a tooth always passes through the same stages in every individual. Since the stages are indicators of maturity and not of the size, they cannot be defined by any absolute length measurements. In it the final scores for each tooth, previously constrained each to be 100, are allowed to vary so that only their sum (or average) over all the teeth is 100. This makes allowance for the different ages at which different teeth maturity scores for girls and boys are given.

Assigning the ratings:

1. The mandibular permanent teeth are rated in the following order: 2nd molar, 1st molar, 2nd bicuspid, 1st bicuspid, canine, lateral incisor, central incisor.
2. All teeth are rated on a scale A-H. The rating is assigned by following carefully the written criteria for each stage and by comparing the tooth with the diagrams and X-ray pictures given for comparison. For each stage, there are one, two or three written criteria marked a, b, c. If only one criterion is given, this must be met for the stage to be taken as reached; if two criteria are given, then it is sufficient if the first one of them is met for the stage to be recorded as reached; if three criteria are given, the first two of them must be met for the stage to be considered reached. At each stage, in addition to the criteria for that stage, the criteria for the previous stage must be satisfied. In borderline cases, the earlier stage is always assigned.
3. There are no absolute measurements to be taken. A pair of dividers is sufficient to compare the relative length (crown/root). To determine apex closure stages, no magnifying glass is necessary. The ratings should be made with the naked eye.
4. The crown height is defined as being the maximum distance between the highest tip of the cusps and the cementoenamel junction. When the buccal and lingual cusps are not at the same level, the midpoint between them is considered as the highest point.

Dental Formation Stages

If there is no sign of calcification, the rating 0 is given: The crypt formation is not taken into consideration.

Stage Description

A. In both uniradicular and multiradicular teeth, a beginning of calcification is seen at the superior level of the crypt in the form of an inverted cone or cones. There is no fusion of these calcified points.
B. Fusion of the calcified points forms one or several cusps which unite to give a regularly outlined occlusal surface.
C. a. Enamel formation is complete at the occlusal surface. Its and convergence toward the cervical region is seen.
   b. The beginning of a dentinal deposit is seen.
   c. The outline of the pulp chamber has the outline of the pulp chamber has a curved shape at the occlusal border.
D. a. The crown formation is completed down to the cementoenamel junction.
   b. The superior border of the pulp chamber in the uniradicular teeth has a definite curved form, being concave toward the cervical region. The projection of the pulp curved shape at the occlusal border horns if present, gives an outline shaped like an Umbrella top in molars the pulp chamber has a trapezoidal form.
   c. Beginning of root formation is seen in the form of a spicule.
E. Uniradicular teeth
   a. The walls of the pulp chamber now form straight lines, whose continuity is broken by the presence of the pulp horn, which is larger than in previous stage the crown height.
   b. The root length is less than the crown height.
- Molars:
   a. Initial formation of the radicular bifurcation is seen in the form of either a calcified point or a semi-lunar shape.
   b. The root length is still less than crown height.

F. Uniradicular teeth
   a. The walls of the pulp chamber now form a more or less isosceles triangle. The apex ends in a funnel shape.
   b. The root length is equal to or greater than the crown height.
- Molars:
   a. The Calcified region of the bifurcation has developed further down from its semi-lunar stage to give the roots a more definite and distinct outline with funnel shaped endings.
   b. The root length is equal to or greater than the crown.

G. The walls of the root canal are now parallel and, its apical end is still partially open.
H. The apical end of the root canal is completely closed.
   a. The periodontal membrane has a uniform width around the root and the apex.

Using the Scoring System

1. Each tooth will have a rating (A-H), assessed by the procedure described.
2. This is converted into a score using the table for boys or girls as appropriate.
3. The scores for all seven teeth are added together to give the maturity score.
4. The maturity score may be plotted on the centile charts (boys or girls as appropriate) where the age of the child is known.
5. The maturity score may be converted directly into a dental age either by reading off on the horizontal

scale the age at which the 50th centile attains the maturity score value, or by using table which has been constructed by this means.

Advantages

Demirjian and Goldstein's method is simple, as it is an orthopantomogram based method and it enables more reliable standardization and has good reproducibility and intra-examiner/inter-examiner reliability.[4]

One of the reasons for the widespread acceptance of this method is that the maturity scoring system that it creates is universal in application, although the conversion to dental age depends on the population being considered. Furthermore, this conversion can be made with the use of relatively small local samples and can reach an equivalent dental age by comparison for different populations.

Limitations

1. Demirjian method use orthopantomograms which are difficult to obtain in young children, due to both technical reasons, as well as legal and ethical considerations.[4]
2. Since simultaneous evaluation of seven left mandibular teeth are required, cannot apply it in children with lacking teeth inborn or acquired.[7]
3. This method may not express, agenesis of teeth, distinctive retardation of dental development (excluding third molars), and systemic diseases and various developmental stages of the tooth.[7]
4. The appreciation of developmental stage may become difficult as the choice of the tooth developmental stage is quite subjective.
5. This method does not give maturity scores for stages 1-4 in case of 1st molar, central and lateral incisor; thus excluding the individuals below the age of 4-4.5 years.[8]

Other Modifications of Demirjian's Method

In 1976, Demirjian developed three more methods. First (DemI976) was based on the same seven teeth; second (DemI976PM,) on four teeth, specifically the first premolar (PMI l, second premolar (PM2), first molar (M1), and second molar (M2); and the third (Dem1976IN2) on four teeth, specifically the second incisive (12), first premolar (PM1), second premolar (PM2), and second molar (M2).[9]

DISCUSSION

One of the most important sub-disciplines of forensic sciences is age estimation and is of paramount importance in medico-legal issues.[2] The broadening frontiers of dentistry have taken the dentist as an expert witness in legal room proceedings and in the field of forensic sciences. However, forensic odontology for long had been a less explored area of dentistry.

Age estimation is an important requisite in some judicial proceedings. Age assessment is required in following circumstances like, asylum seekers of unknown age, young people accused of criminal activities, and convicted criminals whose age is claimed to be less than 18 years prior to sentencing.[7] Age estimation is also useful for human identification and in determining legal age for criminal responsibility. Both are related to local legal requirements and one can be apply that to ageing in both human remains and living people.[10]

However, age estimation is a challenging task. Dental surgeon plays a major role in age estimation. The main objective is to obtain the best standardized method for legal, medical age estimation, which is reproductive, simple and reliable, that we can apply in living and dead.[11]

Scope for Further Research

However, several authors have shown that results are less accurate if one compares another population to Demirjian's standards. Hence, for age estimation based on age, ethnicity/race we need to develop specific standards. Further studies are required to check validity, reliability, and applicability of this method in different populations across the world.

CONCLUSION

Determination of dental age is done by reference to the ever-growing human deciduous and permanent dentitions. The importance of age estimation includes an assessment of minor/major status in individuals without legal documents, Demirjian method, the widely used method with appropriate modifications shall be a reliable method.

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