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Teeth: Important Forensic Tools in Dentistry

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ABSTRACT

Teeth are highly mineralized appendages found in the entrance of the alimentary canal of both invertebrates and vertebrates. They are associated mainly with prehension and processing of food, but they also frequently serve other functions, such as defense, display of dominance and phonetic articulation in humans. Inspection of teeth and jaws has also been used for centuries to identify humans and is an important aspect of forensic odontology. This review article throws a light on those properties of teeth which make then useful as a forensic tool.

Key words: Teeth; Forensic; Forensic Odontology; Dentists; Dental records.

INTRODUCTION

Forensic science is the application of a broad spectrum of sciences to answer questions of interest to a legal system. This may be in relation to a crime or a civil action. The word "forensic" comes from a Latin word, "forum" which means pertaining to the courts of law[1]. Forensic medicine is a branch of medicine that deals with legal aspects of health care,and forensic dentistry is a branch of dentistry that deals with the legal aspects of professional dental practice and treatment, with particular emphasis on the use of dental records to identify victims of crimes or accidents [1].According to Pederson, forensic odontology is a branch of odontology which deals with proper handling and examination of dental evidence and with the proper evaluation and presentation of dental findings in the interest of justice[2]. The British Association for Forensic Odontology (BAFO) notes that forensic odontology is a branch of forensic medicine and, in the interests of justice, deals with the proper examination, handling and presentation of dental evidence in a court of law[2].

The earliest dental identification was made by Agrippina in 49 AD. Agrippina, the wife of Emperor Claudius, ordered the killing of Lollia Paulina; soldiers were instructed to bring back her head. However, Agrippina was unable to recognize Lollia Paulina face by looking at the severed head. She parted the lips and looked for one front discolored tooth to recognize Lollia Paulina. Paul Revere became the first dentist to make a dental identification. He indentified his friend's; Dr. Joseph Warren's body in April 1776 by observing a silverwire-fixed bridge which he had delivered to him in 1775. He is also known as the forerunner of forensic odontology. Dr. Oscar Amoedo is

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known as the Father of forensic odontology. He played a major role in the mass identification in the famous disaster of Paris, The "Bazar de la Charite" disaster on 4th May, 1897. He wrote the 1st texbook on Forensic Odontology of 600 pages – L' Art Dentaire en Medecine Legale-in 1899, which include chapters on dental anatomy, bite-marks, chemical effects on teeth, traumatic lesions, teeth after death[3].

Forensic dentistry is a multidisciplinary team effort by forensic pathologist, forensic anthropologist, forensic dentist, serologists, criminalists, co-operation and co-ordination of law enforcement officials. It is an interdependent science where all of the above mentioned branches have their responsibilities to share.

Why teeth are an important forensic tool?

Skeletal tissues have a very ancient ancestry in the evolutionary record. The basic chemistry of the calcified tissues like bone, antler and tooth (including ivory) is fundamentally the same, although they differ in their mode of growth and microstructure. Tooth enamel is rather specialized and differs from the other calcified tissues in that it is more crystalline and has a negligible organic content. Healthy enamel has zero porosity, apart from occasional growth defects. Although there has been little or no investigation of the porosity of tooth dentine, it is clear that its porosity is low compared with that of bone. Because of the absence of a vascular network in tooth dentine, its relatively low porosity, and the hard shell of impervious enamel that covers the exposed crown, it is generally accepted that teeth are less susceptible to diagenesis (changes undergone by skeletal tissues in burial environment) than bones and, therefore, they represent a more reliable source of ancient DNA and other biomolecular information. Recent evidence supports the view that the potential for post-mortem and post-excavation contamination of teeth is much lower than for bones[4].

Reasons why teeth are known as a valuable in forensic dentistry

1. Teeth endure post/mortem degradation and extreme changes in ambient temperature and pressure better than most human tissues. They form an inert mineralized structure that resists deterioration and hence set up an important method of establishing identity. In a situation involving fire or severe trauma, physical features are often destroyed. Because teeth are heavily calcified, they can resist fire as well as a great majority of traumas[5]. Sweet D, Hildebrand D et al., in 1998, proposed that teeth can survive postmortem circumstances, decomposition, and immersion in water, burial, and fires reaching a temperature of 1100^{0}c[6]. Sweet D, Sweet CH, in 1995, had presented a case report where a victim is burnt body was found in a garbage dumpster. The body seemed to be burnt in gasoline at 200^{0}F for 30-40 minutes. All the physical evidences were destroyed and the body found was 25% of the original volume and weight. Surprisingly, most of the teeth and dental restorations remained infact [7].

2. As a source of DNA – Dental pulps are a rich source of DNA; hence, DNA-PCR can be carried out to identify a persons identity. Sweet D, Hildebrand D et al., in 1998 ,concluded that the neurovascular bundle in pulp is a rich source of DNA. They collected 20 human molars from an oral surgeon and cryogenic grinding was done. The average weight of tooth powder obtained was 1.77gm, i.e 97% yield; average yield of DNA was 30.9 µg. According to them, more recently the extracted tooth, more the yield.[6] Sweet D, Sweet CH in 1995 presented a case report where a victim body was burnt in gasoline at 200^{0}F for 30-40 minutes. After four days, the bone was surgically removed and teeth were extracted. Pliable dental pulps were found in two wisdom teeth and DNA- PCR was done to identify the person[7].

3. As a growth predictor - Liverside HM, Molleson TI, in 1999, studied the skeletal remains of 76 individuals from an 18th century coffin-burried population from Christ Church, Spitalfields, London. The exact age was recorded from parish records Selected age range was from 1-19yrs. Radiographs were taken and developing teeth were dissected

from jaws using dental burs; 354 teeth were isolated, and the tooth length was defined as the distance from cusp tip to developing crown or root. Growth curve was plotted as follows: Most of the growth follows 'S' shaped curve in the pattern of initial fast growth and a mid-root growth spurt [8]. Reddy V.R. (1985) studied the eruption of deciduous teeth in different Indian populations. It was inferred that the order of eruption of teeth in Gulbarga (Karnataka, South India) children was similar to that of Bengali children (West Bengal, Eastern India),except that the mandibular central incisors and second molars erupted earlier in Gulbarga male children [9].

4. As race estimator - Burris BG, Harris EF in 1998, studied the size of palate in 332 half white and half black Americans. It was concluded that in the blacks palate is broader and 'U' shaped especially in canine and 1st premolar region, whereas in whites it is typically convergent shape, elliptical curve in canine and 1st premolar region[10]. Hsu et al ,in 1997, reported two important teeth features: Shovel-shaped teeth and Cusp of Carabelli. The study included 329 Taiwan Chineese and 244 Bunun aborignes children of 12-15years age. Two typical features of Mongloid races found were more shovel shaped incisors and less incidence of cusp of Carabelli, This pattern was seen more in Taiwan Chinese group. This condition is also seen in Chinese, Japanese, Eskimos, North/ South American Indians. Carabelli's tubercle or cusp is an anomalous cuspule on the mesiolingual surface of maxillary molars, appearing in 50% of American whites, 34% of Afro-Americans, and 5 to 20% of American Indains Taurodontism or "bull toothness", especially in maxillary molars, enamel pearls on premolars, and the frequent congenital lack of upper third molars, are commonly noted features in Mongoloids[11].

5. As sex estimator- Lewis A.B. and Garn S.M., in 1960, studied tooth eruption in males and females. Tooth eruption was found accelerated in early maturing girls and the significant correlation between certain stages of tooth formation or movement and menarche was found[12]. Fanning E.A., in 1961, also reported that the completion of tooth crown calcification occurred earlier in females than in males for both deciduous and permanent dentition [13]. Seno and Ishizu in 1973 observed that male teeth are larger than female teeth; canines in females are more pointed with narrow buccolingual width[14].

6. As a Dental age estimator- Dental age is estimated by comparing the dental development status in a person of unknown age with published dental developmental surveys.

Dental age assessment

Principal methods

- Conventional method of counting number of teeth or the last tooth erupted
- Schour And Masseler Method
- Stages By Kraus And Jordan
- Demirjian's method
- Nolla's method
- Moorees method
- Gustafson's method
- Gustafson and Koch method
- Attrition ratio method
- Kvaal et al age estimation criteria

Ancillary methods

- Amino acid racemization studies
- Incremental line and other histology studies
- Dentinal structure identification
- Metal ratio analysis in bone and teeth

• Stages by kraus and jordan

Kraus and Jordan studied the early mineralization in various deciduous teeth as well as in the permanent first molar in the intrauterine life. The development is described in ten stages, denoted by Roman numerals I to

X; the IXth stage includes three stages and the Xth stage includes five stages[15].

• Conventional method of counting number of teeth or the last tooth erupted

It is one of the most commonly implied clinical methods to determine dental age. It is indeed commonly accepted that tooth eruption as an evaluation method for dental age estimation has some limitations. The limitations are: a) they are susceptible to environmental influences such as available space in the dental arch, extraction of deciduous, predecessors, tipping, or impaction of teeth b) they cannot be applied between the ages of three to six years, or past the age of thirteen[16].

• Schour and masseler method

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. The American Dental Association (ADA) has periodically updated these charts and published them in 1982, making it possible to directly compare the calcification stages of teeth on radiographs with the standards[17].

• Demirjian's method of age assessment

The method by Demirjian et al. is useful in estimating the chronological age of children based on their dental age, i.e., of children with unknown birth data, which is often true for adopted children or of children committing legal offenses. The technique may also be used to estimate the age of unidentified skeletons belonging to children. It states eight defined stages in tooth development giving them a score from 'A' through 'H'. This method has been developed from a large random sample of French-Canadian children and is confined to first seven teeth of left lower quadrant. Adding these 8 scores results in the estimation of age[16].

Stages	Description
Stage A	Cusp tips are mineralized but have not yet coalesced
Stage B	Mineralized cusps are united so the mature coronal morphology is well defined
Stage C	Crown is about half formed; the pulp chamber is evident;dentin deposition is occurring
Stage D	Crown formation is complete to dentinoenamel junction; the pulp chamber has a trapezoidal form
Stage E	Formation of inter-radicular bifurcation has begun; root length is less than crown length
Stage F	Root length is at least as great as crown length; roots have funnel - shaped endings
Stage G	Root walls are parallel but apices remain open
Stage H	Apical ends of roots are completely closed and the periodontal membrane has uniform width around the tooth

Advantages[18]

• Predicted dental age is relatively accurate since it is not based on the eruption process of teeth.

• Satisfies most of the ideal requirements

•Based on development of seven or four teeth in mandible, making it quick, easy to use and accurate

•Simplest, most practical, widespread method

•It is based on clearly defined stages

Limitations

•Over-estimation of dental age

Liversidge et al. proved that the Demirjian method yields overestimated results and they consider this due to a positive trend in growth and development during the last 25 years[18]. Prabhakar AR, Raju OS, Panda AK also studied the applicability of Demirjian method in 151 Davangere children of 6-15 years. They also concluded that this technique shows over-estimation of dental age[19].

•Nollas stages of tooth eruption

This method of dental age assessment was proposed by CM Nolla in 1960. It is a type of gradation scale and is one of the dental ageing systems, which are useful for forensic, research and clinical purposes. Development of each tooth is divided into ten recognizable stages and categorically numbered 1 through 10. The sum of the scores of all the teeth is used to define the dental age[20].

Stages

Stages	Description
Stage 0	Absence of crypt
Stage 1	Presence of crypt
Stage 2	Initial calcification
Stage 3	1/3 crown completed
Stage 4	2/3 crown completed
Stage 5	Crown almost completed
Stage 6	Crown completed
Stage 7	1/3 root completed
Stage 8	2/3 root completed
Stage 9	Root almost completed, open apex
Stage 10	Apical part of root completed

Indications

1. Estimation of dental age - Dental age may be assessed either by tooth eruption dates or by the progress of tooth calcification.

2. Application in archaeology - Degree of age-related change in a tooth may be used to estimate the age of human remains.

3. Legal purposes - Tooth calcification rapidly and accurately determines an individual's age for legal purposes.

4. Formulating treatment plans - Dental age is one of the factors taken into account - having particular relevance to the timing of treatment.

5. Diagnosis of genetic anomalies - Certain genetic conditions are characterized by a delay in dental development, eg. Cleidocranial dysplasia.

Advantages

1. Most accurate way of estimating dental age - Teeth progressively calcify in several, easily definable stages so that age can be reliably defined by stage of calcification. It is the least susceptible of these systems to change, both over the centuries and to environmental influences. It is also independent of the somatic growth. Kevin Briffa et al. studied panoramic radiographic records of 120 patients (aged 11 to 14 years), collected from records kept at the School Dental Clinic, Floriana and St Luke's Hospital. Records were matched for age and sex. Calcification of teeth was graded according to Nolla's method. Results obtained were compared to the Nolla's tables to determine how closely Maltese population conforms to these tables. A significant correlation between estimated (dental) age and the chronological age of male school children was found [21].

2. Reliable - Calcified teeth are extremely durable, often surviving conditions which consume all other human tissues, and may be used to age cadavers.

3. Whole dentition analysis – It is applied over the whole dentition leading towards more accuracy.

4. Bolanos scale- It is a modification of Nolla method**.** It is based on Nolla's tables applicable to three and four teeth. This scale is more practical for epidemiological studies [21].

5. Moorees cf method - This is a graphic method where dental maturation has been divided into 14 stages, ranging from initial crown formation to apical closure. It is a quantitative numerical method that performs very well in individuals from 4.7 to 20.7 years of age. For estimating dental age, mandibular teeth are generally used because the overlapping of osseous structures hinders analysis of maxillary teeth. The values of ages corresponding to the formation stages are averaged obtaining the dental age through the mean. This method presented the highest correlation coefficient between dental age and radiographic age with a tendency to overestimating the radiographic age [22].

6. Gustafson's method - An early age estimation technique was proposed by Gustafson. It is based on the measurement of regressive changes in the teeth such as amount of occlusal attrition, amount of coronary secondary dentin deposition etc. For each of these parameters, Gustafson has assigned scores from 0 to 3,and by adding these, an overall score was obtained which was linearly related to an estimated age[23].

• Gustafson linear regression formula for age estimation was:

Age = 11.43 + 4.56 X **X= Overall score**

Later on, Johanson modified the formula, evaluated six criterias and made it most widely accepted among forensic odontologists. The equation given was:

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

Six criteria

1) Attrition, wearing down of incisal and occlusal surfaces (**A)**
2) Secondary dentin formation, filling of pulp canal with hard tissue **(S)**
3) Paradontosis, changes in supporting periodontium leading to loosening of teeth, abscess formation and tooth loss (**P)**
4) Cementum apposition especailly. at root apex **(C)**
5) Root resorption, delineated areas of cementum and dentin being resorbed by special cells **(R)**
6) Apical root transparency, transparent dentin seen in root **(T)**

Attrition Ratio Method

Sumit Seth et al[21] from the Department of Forensic Medicine & Toxicology, L.H.M.C & Smt. Sucheta Kriplani Hospital, New Delhi, in the year 2001 – 2002 proposed a method to estimate the dental age. The central maxillary incisor teeth were extracted from the dead bodies of ages 25 to 75 years. The formula proposed was:

• Index value of attrition = $\frac{aX100}{A}$

• 'a' is width in mm of attrited teeth

• 'A' is the width in mm of teeth at the cervical margin

• The Inference was that in Group A (25 – 35 years), the index value of attrition ranged from 35.5 to 60.0**.** In Group B (35-45 yrs), the index value ranged from 34 to 86**.** In Group C & D the values ranged from 63 to 92 & 87 to 94.5**.**

On this basis, an equation was formulated to determine dental age,

Age = 0.606 x Index value of attrition – 0.474

Kvaal Age Estimation Criteria[25, 26]**:** In this method, pulp-to-tooth ratio was calculated for six mandibular and maxillary teeth. Teeth included were 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. Using intraoral periapical radiographs, pulp-root length (R), pulp-tooth length (P), tooth-root length(T), pulp-root width at cemento-enamel junction (A),pulp-root width at mid-root level (C) and pulp-root width at midpoint between levels C and A (B) for all six teeth were measured. Finally, mean value of all ratios excluding T (M),mean value of width ratio B and C (W) and mean value of length ratio P and R (L) were substituted in the given formula:

Age = 129.8 – (316.4 X M) (6.8 X (W-L))

Ancillary techniques of dental age estimation

• **Aspartic acid racemization** - Racemization of aspartic acid in dentin protein during the human lifetime progresses with age. The extent of racemization of aspartic acid in coronal dentin of normal permanent teeth can be used in forensic odontology to estimate the age of an individual at the time of death. Amino acids which contain at least one asymmetric carbon atom in their molecules show optical activity [i.e., the D- and L-enantiomers of these molecules rotate the plane of polarized light to the right (D) or to the left (L)]. Optically active amino acids in most living organisms consist initially only of their L-enantiomers. In time, these L-amino acids are partly converted to the D-enantiomers until equilibrium mixtures of the D- and L-enantiomers are attained. The racemization of aspartic acid in bone is generally faster than that of other amino acids (aspartic acid > alanine >glutamic acid > isoleucine - leucine). Studies have shown that D-aspartyl residues accumulate with aging throughout human life in the metabolically stable protein in tooth enamel, dentin, and lens. The accumulation rate of D-aspartyl residues (i.e., racemization rate) is temperature-dependent in vivo and post mortem. As post mortem temperatures of cadavers rapidly reach the temperatures of the preserving environment, the racemization rate decreases greatly. In 1976, Helfman and Bada used this information to study age estimation by comparing D/L aspartic acid dental ratios in 20 subjects. A high coronary D/L ratio was noted in the younger age group, decreasing with age presumptively due to environmental changes[27]. In 1985, Ogino et alreported this application in forensic odontology specimens for age determination at the time of death[28]. In 1990, Ritz et al studied the extent of aspartic acid racemization in dentin for age determination at the time of death, concluding it as a more accurate method for the determination of age than other aging parameters[29]. In 1991, Ohtani and Yamamoto studied this aspartic acid relationship in lower central incisors and first premolars and found good correlation between Asp D/L and actual age. It was concluded that better age estimations could be achieved with fractionating the total amino acid fraction (TAA) into an insoluble collagen fraction (IC) and a soluble peptide fraction (SP). Soluble peptide fraction contains higher aspartic acid and glutamine. SP appeared to provide the most reliable age estimation because of a high racemization rate — roughly three times that of TAA [27].

• **Incremental line analysis:** Dental development in humans begins prior to birth and continues throughout adolescence. Like many biological systems, hard tissue formation is characterized by a circadian rhythm. Developmental rate and time are permanently recorded by incremental lines in enamel and dentine, which remain unchanged in these tissues for millions of years. Given that dental remains are the most common, well-preserved type of fossil evidence for extinct species of primates, examination of incremental growth processes sheds new light on the evolutionary developmental biology of early humans. Counts and measurements of these short- and long-period lines provide information on the rate and duration of enamel and dentine secretion, which may be combined to determine the total crown formation time and the rate and duration of root extension. The neonatal line is a particular band of incremental growth lines seen in histologic sections of deciduous teeth. It belongs to a series of a growth lines in tooth enamel known as the striae of Retzius. The neonatal line is darker and larger than the rest of the striae of Retzius. It is caused by the different physiologic changes at birth and is used to identify enamel formation before and after birth. These lines are formed in enamel and dentine at the point of birth. Therefore, only teeth that are developing at birth can exhibit neonatal lines. All the primary teeth are forming at birth; first permanent molar is just beginning calcification at or near birth. The enamel develops before dentine, so, depending on when the first permanent molars start their development, the enamel would probably have neonatal lines and the dentine may or may not have. Different teeth developing in one individual give the same pattern of incremental lines which is distinct from that of another individual. So, they are the "Fingerprints" of enamel development. Incremental line analysis is usually done on ground sections of longitudinally sectioned dentition. [29] [30]. Anders Retzius in 1837 described incremental brown striae in the enamel of teeth. In 1991, Skinner and Anderson studied the cranium of a missed native Indian child in British Columbia, Canada. They correlated these lines with stressors in life[30]. Thomas Cook DC also reported that incremental line analysis appears to complement dental eruption data. Lipsinic et al. studied correlation of age and incremental lines in cementum of human teeth. They found correlation between the number of lines and age[29]. Singh and Gunberg combined bone section histology with dental histology and concluded the lalter as a valuable comparative age determination method[31].

- **Dental structure identification:** The microscopic age changes of dentin are characterized by the fact that an increasing number of dentinal tubules are obliterated by mineralized tissue with age. The occluding material is homogeneous and consists of non collagenous matrix and small hydroxyapatite crystals. The formation and pattern of age-related intratubular dentin is important from the forensic point of view, which starts at the apex of teeth and continues towards the coronal direction with increasing age. In the coronal dentin, the intratubular mineralization will not lead to complete obliteration of the tubules until patient is in their 70s. Carrigon PJ et al (1984), in a SEM study, studied dentinal tubules in 30 freshly extracted human maxillary central incisors and concluded that the number of dentinal tubules decreased with increasing age[29]. Carr et al in 1986. confirmed dentition in recovered remains from burned wreckage of a gasoline truck involved in a transportation mishap. Identification of the specimens as dentition was based on the presence of dentinal tubules In addition to dentinal tubules, SEM provided profile of elements present within the dentinal tubules which identified particular type of dental material. [32]. Fairgrieve, in 1994, reported a similar case involving SEM on incinerated teeth to evaluate parallel striations in tooth enamel and dentine as evidence of previous dental restorations[33].

- **Metal ratios:** Under conditions of normal calcium metabolism, strontium/calcium ratios (Sr/Ca) have been shown to reflect the trophic level of contemporary and recent terrestrial fauna. These ratios, therefore, offer a potential means of studying fossil ecosystems in medicine. However, in dentistry, the literature is very sparse. LT Humphrey et al studied Sr/Ca ratio across neonatal line. Neonatal line separates enamel that initiate mineralization prior to birth and enamel that initiate mineralization in early postnatal period. It was concluded that stronitium level decreases at birth in breastfed infants and the level increases in infant-fed formula from cow's milk[34].

CONCLUSION

Teeth record information that remains throughout life and beyond. Teeth may also be used as weapons and, under certain circumstances, may leave information about many important things used in forensic odontology. It is because of this unique nature of this hard mineralized tissue that we can wind up this article by concluding that a tooth is indeed a very important forensic tool. So, dental professionals have a major role to play in keeping accurate dental records and providing all necessary information so that legal authorities may recognize malpractice, negligence, fraud or abuse, and identify unknown humans.

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