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Review Article

Forensic dentistry- A deep dive in the drop

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ABSTRACT

Teeth can be put to a lot more use than just understanding and evolving dentistry. Teeth can withstand tremendous pressure and extreme conditions providing for an incomparable piece of evidence. The comparison of the ante-mortem and the post-mortem evidences can be used to establish an identity of the required personnel. The oral cavity provides an excellent field to work on when it comes to human identification, age estimation and sex determination. The Bichat's fat pad, lips, maxillary bones and the teeth protect the palatal rugae hence making them resistant to decomposition and incineration. The palatal rugae are characteristic to every individual. Just like the fingerprints, lip prints are permanent and constant for every individual. Bite marks can be found either on the attacker or the perpetrator. Both lip prints and bite marks account for important evidence for human identification found at the site of crime in the cases of sexual abuse. As the oral cavity serves as a useful source of DNA, latter can be extracted from saliva, the oral mucosal cells and the teeth. This DNA is used for PCR analysis. Dental structures can prove as useful indictors in determining the individual's chronological age by analysing the tooth development. The sexual dimorphism elicited by various teeth of the human dentition play a major role in sex determination of the individual. The various recent advances like- facial reconstruction, dental identification methods, tongue prints, ameloglyphics make forensic dentistry a convenient and an effective tool in human identification. Forensic dentistry should not only be restricted to the dentists but various team involved in investigations and justice should also be exposed to this arena to avoid any biased and negligent decision making.

1. Introduction

In the era of newly emerging professions, dentistry has spread its branches over years and is still growing. One such branch of dentistry is forensic dentistry. Keiser-Neilson in 1970 defined forensic dentistry as "that branch of forensic medicine which, in the interest of justice deals with the proper handling and examination of dental evidence and with the proper evaluation and presentation of the dental findings".[1] It holds a firm ground as any other investigatory field. As teeth are the hardest known tissue and do not decompose like any other part of the body, this branch happens to be one of the most reliable choices of investigation in the medicolegal cases and disaster victim identification. Unfortunately, this is a less recognised topic of interest amongst the undergraduates. Like in any other field, modern advancements in this branch of dentistry have drastically enhanced its effectiveness. This article aims at various methods of identification, age estimation and sex determination along with the various recent advances that have emerged over the years making forensic dentistry a convenient choice for human identification. Not only forensic dentistry provides aid in human identification, it also plays a part in legal assistance. Thereby the main aim of this article is to portray forensic dentistry in such a way so as to provide more recognition to this field and introducing

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it as a career option after graduation along with various modern tools used to make decision making more thorough and definite.

2. Forensic Dentistry in Human Identification

2.1. Comparative dental identification

The teeth arrangement and morphology are unique for every individual. The central dogma of dental identification is the comparison of ante-mortem and the post-mortem records to reveal the identity of the required personnel. Teeth can undergo adverse post-mortem changes which can degrade and disrupt other body tissues. The ante-mortem records are obtained from the dentist of the record. The written descriptions on the radiographs and dental structures produce a post-mortem record. Dental caries, restorations, implants, dentures, prosthesis, teeth alterations like talon cusps, developmental defects like dentinogenesis imperfecta, amelogenesis imperfects, changes in tooth colour as in dental fluorosis are the dental evidences used in the comparison. To avoid any confusion between ante-mortem and the post-mortem records, the films are marked with the rubber dam punch - ante-mortem films, one hole and the post-mortem film, two holes. Since the so called non restorative cases are likely to be more common, a systemic criterion of comparison is necessary. This is achieved by examining each tooth and its surrounding tissues.

Similarities and discrepancies should be a matter of concern in the comparison process. There are two types of discrepancies- Explainable and Unexplainable. Time elapsed between ante-mortem and post-mortem relates to the explainable discrepancies. For example, the disto-occlusal restoration now being mesial-occlusal-distal, extractions.

The American board of Forensic Odontology limits the conclusions reached whilst dental identification to the following four conclusions.

1. Positive identification: there are no unexplainable discrepancies between the antemortem and the post mortem records and they match in sufficient detail to establish the identity of the same individual. There should be at least 12 coincident features - Probability of coincidence with another person ≤ 1/10,000.
2. Possible identification: the identity cannot be established positively due to the quality of the post-mortem records or the ante-mortem evidences despite consistent features.
3. Insufficient evidence: the available information is not sufficient to conclude.
4. Exclusion: there is clear inconsistency between ante-mortem and post-mortem records.[2,3]

3. Postmortem Dental Profiling

In the absence of ante-mortem evidences where other methods cannot be used, post-mortem dental profiling can be considered as an appropriate choice. This includes limiting the pool of population by a forensic dentist to which the dead individual is likely to belong thereby arising a possibility of the ante mortem records to be found in that area. Information on the deceased's age, ancestry background, sex, socio-economic status, occupation, dietary habits, habitual behaviours and occasionally on dental or systemic diseases is obtained. Skull is of great significance in determination of sex and ancestry. Skull shape and form are characteristic for every race. There are three major categories in which the forensic dentists determine race - Caucasoid, Mongoloid and Negroid. Cusps of carabelli, shovel-shaped incisors and multi-cusped premolars are the additional characteristics that can assist in determining ancestry.[2]

4. Rugoscopy

Palatal rugae are the ridges, wrinkles or folds present on the anterior portion of the hard palate on either side of the midpalatine raphe. The Bichat's fat pad, lips, maxillary bones and the teeth protect the palatal rugae hence making them resistant to decomposition and incineration. Palatal rugae are formed during the third month of the intrauterine development and persist throughout the life like fingerprints, palatal rugae are characteristic to every individual including twins. Rugoscopy is defined as the analysis and study of shape, length, number, merging pattern and direction of palatal rugae.

According to *Thomas et al.*[1] rugae patterns can be classified as diverge, converge, curve, wavy, straight and circular. *Ohtani et al.*[3] listed three conditions- palatal height changes, poorly demarcated rugae indicated by flat and poorly accentuated ridges and lastly lack of uncomplicated patterns. The presence of other elements such as incisive papilla, the shape of the mid-palatal raphe, and the palatal tori can supplement the study of palatal rugae. According to a study on Japanese population it was found that females possess fewer palatal rugae as compared to males.[4]Identification by rugoscopy has a percentage accuracy of up to 94%.[3]

5. Cheiloscopy

Similar to fingerprints, lip prints are important evidence at the crime site. Except in the monozygous twins, lip prints are permanent and constant, therefore unique for every individual.[3] The study of characteristic pattern of the lips formed by a series of elevations and depressions is referred to as cheiloscopy. According to *Renaud's classification,* there are 10 types of lip prints- designated by alphabet A to J.[3]Capital letters being used for the upper lip and the

lowercase, for the lower lips. *Tsuchihashi et al*[1] classified grove patterns in the lip into six different types- Type 1- clear-cut vertical grooves running across entire lip; Type I' similar to type I but entire lip is not covered; Type II -branched grooves; Type III- intersected grooves; Type IV- reticular grooves and Type V- morphologically undifferentiated. *Rachna V Prabhu et al.[1]*, conducted a study amongst dental students concluding that type V pattern as the most common in occurrence and recorded trifurcation, Bridge or H pattern, horizontal lines, cartwheel, pineapple skin and multiple branching appearances for the first time.[1] Thus, emphasising the need for sub classification of type V for a more accurate investigation.

Vahanwala et al.[4] proposed a criterion for sex determination using lip prints as- • Type I, I': Pattern dominant & female • Type II: Pattern is dominant & female • Type III: Pattern present &; male • Type IV: Male • Type V: Varied pattern & male • Same patterns in all quadrants – female.

6. Bite Marks

The uniqueness of the human dentition for every individual has been determined by many studies. The imprint of the cutting edges of the teeth on a substance as a result of jaw closing is defined as a bite mark.[5] A central zone of contusion is observed within the teeth marks. Extravascular bleeding can be seen directed from the periphery of the bite mark towards the interior due to the tooth pressure caused upon the tissues.[3] A typical human bite varies from 25 - 40mm in diameter.[3] Bite marks can be found either on the attacker or the perpetrator. At times they can be found on inanimate objects at the crime site.[5] Skin and soft tissues of the entire body are the most common areas where human bite marks are likely to be found in the victims.[5] In females, bite marks are found on breasts and thighs secondary to a sexual abuse whereas in males, they are found on arms and shoulders.[5] Under defensive circumstances, arms and hands are usually bitten.[4] The *American Board of Forensic Odontology* (ABFO) has set various guidelines for the analysis of bite marks. They include recording the description of the bite mark regarding the demographics, location, shape, size, colour, type of injury and any other information of interest at the time of collection of dental evidence.[5] Evidences from the victims are collected in the form of photographs, salivary swabs, impressions and tissue samples. Even evidences from the suspect(s) including history, photos, extraoral examination, intraoral examination, impressions, sample bites and study casts are a requisite.[5] Lighting and the utilization of a scale in the photo should be considered while photographing and documenting the bite site to provide an accurate account of the size.[5] The physical and biological findings should be documented immediately as they deteriorate from the moment of the actual bite.[5] The double cotton swab technique can preferably be used to collect the saliva deposits in the skin at the time of biting. Since dry saliva is hard to detect, amylase test is performed to detect its presence. Vinyl polysiloxane, polyether are the recommended impression materials for obtaining the imprints for fixed prosthesis and registering all the irregularities produced by the teeth upon the skin.[3] *Cameron and Sim* [1] classified bite marks on the basis of agent and material. According to *McDonald,*[1] bite marks are classified as tooth pressure, tongue pressure and tooth scrape mark. *Vander Veldon. A et al.*[1] used image perception technology for bite mark analysis and crime investigation. The additional colouring of images, pseudo three-dimension imaging proved to be the advantages of this technique, thereby improving its accuracy.

7. DNA In Dental Identification

As the oral cavity serves as a useful source of DNA, latter can be extracted from saliva, the oral mucosal cells and the teeth. The main source of DNA is blood, though it may be unavailable for analysis in some situations. Pulp tissue's abundance and its invulnerability to get affected by any non-human DNA makes it the most widely used option.[3] The pulp tissue collection is carried out in three ways- crushing, horizontal or vertical tooth sectioning, through an endodontic access.[3] In the cases where the pulp is endodontically obturated, dentine or cementum are used as an alternative. *Sweet and Hildebrand*[6] pioneered extraction of DNA by tooth crushing through cryogenization. There are two kinds of DNA that can be extracted.[6]

Genomic DNA- it is found in the nucleus of the cell. Since the red blood cells are nuclei deficit, they lack DNA. The structures of the enamel, dentine and pulp persist even after the decomposition of the other body tissues. Hence DNA extraction from the calcified tissues is essential. Teeth serve an outstanding source of DNA, so much so that even the root-filled teeth provide sufficient biological material for PCR analysis.[2]

Mitochondrial DNA (mtDNA) - it is sequence of building blocks in the cells which assists in identification. The mtDNA has a high copy number in each cell due to high number of mitochondrial in most cells. In cases where the genomic DNA is too degraded to be analysed, mtDNA will be present in a generous amounts. Along with the advantage of having a high copy number, another advantage is that the mitochondrial DNA is maternally inherited. This pattern of inheritance is of great implication in identification where the ante mortem records are absent as all the siblings and the maternal relatives will share the same mtDNA sequence and barring mutations.[2]

8. Age Estimation

Dental structures can prove as useful indicators in determining the individual's chronological age. The age

of children including those of foetuses and neonates can be determined by analysing the tooth development and subsequently comparing it with the developmental charts. *Ubelaker*[2] developed the charts which had a graphical interpretation of the dentition development ranging from 5 weeks in-utero to 35 years of age, involving all the three types of dentitions- deciduous, mixed and permanent. The eruption dates of the teeth are highly variable when determining the sub-adult ages, in situations like these, the actual developmental stages of the teeth offer more accuracy.[2]

The first method of age estimation of a person from the teeth was published by *Gustafsonp*[7] in 1950. Based on changes associated with hard dental tissues that progress with advancing age, six criteria were listed- occlusal wear, secondary and tertiary dentin layers, cement thickness, the extent of root resorption, the length of the root transparency and the height of gingival attachment. According to the intensity of all these factors a score from 0-3 was assigned. Subjective results were recorded as the scores were not included in an integrating scale. This method had a mean error of 14.2 ± 3.4 years. On the other hand, *Lamendin et al.*[8] established a technique using the single rooted teeth for age estimation of adults. This technique involved analysis of two age related parameters- gingival recession and root transparency. Root transparency is absent in the individuals below 20 years of age and results from the formation of hydroxyapatite deposits within the dentinal tubules. The maximum length of root transparency was measured on the vestibular side of the root as it was most apparent. The mean error of this method was 8.9 ± 2.2 which was significantly lower than that of the Gustafson's method.[3] Age estimation using the superimposed cementum layers was also one method. The chronological age of an individual was determined by the number of cementum layers deposited and to the age of tooth eruption.[3] *Czermak et al.*[3] relieved the factor of human errors caused due to fatigue and subjectiveness of this method on the basis of software-mediated obtainment of the images that ensured best location of cement layers at microscopic level.

Dermirjian et al.[9] developed a method based on the assessment of the degree of mineralisation. Depending on the degree of development, the teeth were designated alphabet from A-H and a score was assigned depending on the gender. The sum of the teeth was added up and a conclusion was made after comparing it to the conversion table. A method based on radiological and histological changes occurring in the mandibular bone was introduced by *Mohite et al.*[3] As the age advanced, the mandibular ramus was seen to increase in length in the radiograph, mental foramen being taken as a point of reference. The process became gradual after 50 years of age and a decrease in the alveolar processes was noticed when measured in a craniocaudal direction. There was an increase in the porosity of the cortical bone as a consequence of expansion of the haversian canal system resulting from increased remodelling with osteons and decreased osteoblastic activity with advancing age. The number of concentric laminas per osteon decreased especially in individuals above 50 years of age.[3]

9. Radiography

Radiographic features prove to be of immense help in age estimation. Different ages have characteristic dental features associated to them which are seen on a radiograph making it convenient for the investigator to find the age of the required individual. For example, the presence of third molar occurs only in individuals above 18 years of age, the pulp chamber starts to decrease with advancing age.

Parameters like eruption sequence appearance of tooth germs, extent of mineralisation, degree of mineralisation, degree of crown and root completion, degree of root resorption of deciduous teeth, open apices, pulp to tooth ratio, volume of pulp chambers and root canals and third molar are estimated through various radiographic techniques like intraoral periapical radiographs, lateral oblique radiographs, panoramic radiographs and cephalograms.[1] X ray images of developing teeth is necessary for all these techniques.

The odontological age estimation triad is an important consideration which is enumerated as follows-

1. The subject
2. The selected dental developmental survey
3. The legal considerations[1]

There are four established methods for age estimation by radiography-

1. *Schoulr and Masslers method*[1]- The analysis of development of deciduous dentition led to the evolvement of 21 chronological steps from 4 months to 21 years. This data got published in the ADA and is updated from time to time. *Moorer, Fanning and Hunt method*[1] - The 14 stages of mineralisation for development of single and multirooted teeth are used for age estimation.
2. *Demirijian, Goldstein and Tanners method*[1] - They determined 8 stages of mineralisation from A-M using the orderly rating of seven mandibular- second molar (M2), first molar(M1), second premolar (PM2), first premolar (PM1), canine(C), lateral incisor(I2), central incisor (I1). Correlating this data, the age was identified.
3. *Nolla's technique*[1] - This technique included evaluation of calcification of permanent teeth in ten stages and can be used for assessing development of each tooth in the maxilla and mandible.

10. Sex Determination

The conventional method of sex determination is the clinical examination of the dental structures. The permanent canine teeth and the distance between the cusp tips illicit the maximum degree of sexual dimorphism and hence can be considered as the centre of concern while determining the sex of an individual. A study by *Garn et al*[4] confirmed that the mandibular canine showed greater extent of sexual respect of sexual dimorphism with respect to the maxillary canine in different ethnic groups whereas on the other hand *Kuwana*[4] in 1983, *Mizuno*[4] in 1990 concluded the opposite of this study. Therefore, the controversy related to this matter still continues. The mesio - distal width of mandibular canines was significantly greater in males than in females as per the reports by *Rao et al.*[4] Various anatomical structures like the mandible, foramen magnum, paranasal sinuses, frontal sinus, maxillary sinuses and mastoid processes are evaluated along with the canines as these structures too possess sexual dimorphism.

The mandible differs in shape and size amongst both the sexes. Attributed to the sex, nutrition and physical activity females have a smaller mandible and relatively a less thickened bone. The difference in the masticatory forces between the males and females affects the expression of mandibular dimorphism in terms of the relative development like size, strength, and angulation of the masticatory muscles. Females have downward and a backward rotation of the mandible which results in an increased value of the gonial angle whereas the males have forwardly rotated mandible and a lesser gonial angle. The gonial angle shows variations in life- being obtuse at the time of birth, decreasing as the individual grows up and ultimately increasing again in the older age. A CBCT can be useful in determining various factors like length and breadth of the ramus, gonion–gnathion length, gonial angle, bigonial breadth, and bicondylar breadth for sex determination.[10]

The cranial base is resistant to physical insults because of its thickness, anatomical position and compactness due to this reason it acts as a guide in forensic dentistry Foramen magnum (FM) is a 3D aperture present within the basal central region of the skull. It is a transition zone between the skull and the spine.[10] The usefulness of foramen magnum in sex determination was first reported by *Teixeria*[11] in the year *1982. Gunay and Altinkok (2000)*[12] assessed the area of FM in an inhomogeneous sample of male and female skulls and concluded that the mean area of FM is greater in the males however this information does not hold much significance in forensic dentistry.

The paranasal sinuses (PNS) remain unaffected by any physical injury to the skull and other craniofacial bones. Various studies show that the jaw sinuses in males are considerably larger than in females. The first radiographic comparison of PNS in the body was conducted by *Culbert and Law in 1927.*[10] *Wanzeler et al in 2019*[13] co-related the volumetric analysis of the maxillary, sphenoidal, and frontal sinuses using CBCT scans with FM measurements. A conclusion was made based on this co-relation stating that there was an accuracy rate of 96.2% and 92.7% for males and females, respectively after summing up the volumes of maxillary, sphenoidal, and frontal sinuses. The accuracy exceeded to 100% on correlating the sum of the three estimated PNS with FM measurements.[10]

The frontal sinuses are unique in every individual even in the monozygotic twins. The frontal sinus index is the tool used in sex determination. The nasion–sella line is analysed horizontally on a lateral cephalogram radiograph. The other parameters are the width and height of the frontal sinus, anteroposterior diameter, total width of the sinus, inter-sinus width, the distance between highest points between two frontal sinuses, and distance between the highest point of left frontal sinus and the maximum lateral limit measurements. The different parameters of frontal sinus were measured using reconstructed CBCT scans by *Choi et al*[14] in *2018* reporting that the frontal sinus analysis determines sex with up to an accuracy of 80%.

The maxillary sinuses are the first paranasal sinuses to develop. It appears at the end of second month of intra uterine life and is completed by 18 - 20 years. A study using CBCT by *Tambawala et al.*[15] showed statistically significantly higher values of the height, width, and length dimensions for both left and right maxillary sinuses in males. The height of the maxillary sinus happens to be the best predictor for sexual dimorphism. *Urooge et al*[16] showed the efficiency of this method to be 74% in females and 68% in males, with an overall accuracy of 71%.

Like the foramen magnum and the paranasal sinuses, the mastoid process too is resistant to the physical injuries. In the cases where the skull is fractured, the mastoid process is the area of great interest for macroscopic evaluation during investigation. Males have a larger mastoid process with a vertical tip while females have an inward facing tip. A study by *Amin et al* concluded the accuracy of this method to 90.6%.[10]

11. Recent Advances in Forensic Dentistry

Facial reconstruction: This method is used to produce a close resembling image of the deceased individual.[17] The computerised facial reconstruction method uses a laser video camera to acquire the skull. A fully shaded 3D surface of skull data is imaged. Face can be drawn via computer software like Vitrea 2.3 version volumetric visualization software. The 3D computer tomography (CT) is considered to be more accurate than the 2D CT technique and the direct imaging performed on CT slices.[18]

Denture Identification Method: The denture possesses a great degree of resistance to the high temperatures, providing a medium of identification in forensic dentistry. A denture can only reveal a positive identity if it is

marked. Markings are based on the two methods: the surface marking method and the inclusion method. The metal identification bands, computer printed denture mislabelling system, lead paper labelling, embedding the patient's photograph in the dentures, denture barcoding, T bar, laser etching, lenticular card system, radiographic identification tags, and electronic microchips are the components of inclusion method. This method provides more predictable results and last longer than the surface markings. [19]

Tongue prints: Like the fingerprints, the dorsal surface of the tongue is morphologically unique to every individual. The ante-mortem records should be available for this technique to be successful. The lingual impression along with its photographic records are secure method for identification in forensic dentistry. [20]

Tongue prints can be recorded using the following techniques-

1. Visual identification to inspect basic features of the tongue such as colour, surface texture, mobility, and any other special characteristics.
2. Alginate impression followed by cast preparation
3. Obtaining digital images of the tongue through digital software.
4. Analysis of sublingual vein
5. Histological exam [21]

Ameloglyphics: The study of enamel pattern is termed as ameloglyphics. The enamel rod pattern is characteristic to every individual and show gender variation hence can aid in human identification. A study by *Manjunath et al* concluded that the branched wavy sub pattern was the most common type by visual analysis after studying the enamel pattern of left maxillary canine and first premolar in 30 male and 30 female volunteers using cellulose acetate peel technique. [1]

12. Forensic Dentistry as Legal Assistance

Corpse identification in a crime or disaster mass fatality is a crucial task and demands keen knowledge and expertise of the investigator. The cases where face and the body of the individual are severely damaged or injured, like in fires, disaster, road side accidents, the cranium and the oral cavity serve as evidence in such challenging conditions. These evidences contribute significantly to establish the profile of the required individual. Apart from corpse identification forensic dentistry plays a part in uncovering the criminals especially in the cases involving sexual assaults. The knowledge of forensic dentistry is essential amongst the police personnel, lawyers and the judges for making an accurate interpretation of the ante-mortem and the post-mortem records. [22] Lack of knowledge related to this field can lead to an incompetent assessment of the records thereby compromising the pursuit of justice. [23] A systematic and thorough investigation by the team can indefinitely provide justice to the victims, apt retribution on the criminals and the unrecognised bodies could finally be claimed by their families.

13. Conclusion

Forensic dentistry is still an underappreciated sector even in the 21^{st} century where new fields are flourishing significantly. The sole purpose of this article was to provide more recognition to this field and set a firm ground in dentistry. Among the undergraduates, forensic dentistry is often an overlooked domain, this article was to change that perspective among the budding dentists to portray this sector as a rather unique yet worthy option for masters after Bachelors of Dental Surgery. Not only the article focused on awareness among the dentists but also amongst the various teams involved in investigations and justice like the police and the judges. It is equally important to educate them as well on this topic to avoid any conflicts and injustice among decision making and to trace back the crime scene efficiently. Even the slightest of negligence on the part of a forensic dentist, police or the judge can end up changing the whole face of the scenario. This could put one's reputation at stake and could have some serious repercussions. Therefore, not only a dentist should have a deep knowledge of this arena to prevent any medicolegal case getting filed on them but also it shouldn't be ignored by police and the judges so as to prevent questions being raised on the legal code of ethics.

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15. Conflict of Interest

None.

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