Dental Profiling & Their Recent Advancements In Forensic Odontology

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Abstract:

Forensic Odontology, the application of dental science in legal investigations, has emerged as a crucial discipline in identifying victims & perpetrators through dental evidences. Dental profiling, a specific branch of Forensic Odontology, involves the analysis & interpretation of dental characteristics for establishing individual identities. This paper explores the recent advancements in dental profiling techniques & their significance in modern forensic investigations. Traditional Dental Profiling methods, such as- Dental Records Comparison & Radiographic analysis, have been instrumental in victim identification & criminal investigations. However, the advent of digital technologies has revolutionized the field, offering more accurate, efficient & comprehensive approaches. Digital Dental Imaging & Analysis Techniques, including – Intraoral scanners, 3D imaging & Computer-aided design/Computer-aided manufacturing (CAD/CAM), have facilitated precise data acquisition, virtual treatment planning & comparative analysis. Biometric dental identification techniques, such as – Tooth Print analysis, Bite Mark analysis, & Lip Print analysis (Cheiloscopy), have gained prominence due to their ability to link individuals to crime scenes through unique dental characteristics. Additionally, Genetic profiling & DNA Analysis from dental pulp & root canal remnants have emerged as powerful tools for establishing identities & ancestry determination. Age estimation & Facial reconstruction techniques have also benefited from advancements in Dental Profiling. Dental age estimation methods, coupled with digital imaging & analysis, have enhanced the accuracy of age determination, while forensic facial reconstruction using dental data has facilitated victim identification & criminal investigations. Despite these advancements, several challenges persist, including legal & ethical considerations, data storage & security concerns along with the need for standardization & quality control measures. The paper also discusses the emerging technologies & research areas that hold promise for further advancing dental profiling in Forensic Odontology. Ultimately, the advancements in dental profiling techniques have significantly improved the reliability & efficiency of forensic investigations, victim identification & criminal justice processes. This research paper provides a comprehensive overview of these advancements, their applications, & their potential impact on the field of Forensic Odontology.

Keywords: - *Victim Identification, Criminal Investigations, Digital Dental Imaging, Tooth Print Analysis, Bite Mark Analysis, Cheiloscopy, Genetic Profiling, Legal Considerations.*

I.   Introduction

Forensic odontology has emerged as a vital branch of forensic science, leveraging the unique characteristics of teeth & dental records to aid in criminal investigations & victim identification processes. Within this domain, Dental Profiling plays a crucial role by analyzing & interpreting dental evidence to establish individual identities. Traditional dental profiling techniques have relied on methods such as- comparing ante-mortem & post-mortem dental records, radiographic analysis, & the examination of dental restorations & anomalies. However, recent technological advancements have revolutionized the field, offering more accurate, efficient & comprehensive approaches to dental profiling. The advent of digital dental imaging & analysis techniques, such as- Intra-oral scanners, 3D imaging & Computer-aided design/Computer-aided manufacturing (CAD/CAM) has facilitated precise data acquisition, virtual treatment planning & comparative analysis. These advancements have significantly improved the reliability & efficiency of dental evidence evaluation. Additionally, biometric dental identification techniques including – tooth print analysis, bite mark analysis, & lip print analysis (Cheiloscopy) have gained prominence due to their ability to link individuals to crime scenes through unique dental characteristics. Furthermore, genetic profiling & DNA analysis from dental pulp & root canal remnants have emerged as powerful tools for establishing identities & ancestry determination. Dental age estimation & Facial reconstruction techniques have also benefited from these advancements in

dental profiling. Accurate age determination & facial reconstruction using dental data have facilitated victim identification & criminal investigations, particularly in cases involving decomposed or, fragmented remains. While these advancements have significantly enhanced the capabilities of forensic odontology, several challenges persist, including – legal & ethical considerations, data storage, security concerns & the need for standardization & quality control measures.

II. Historical Background

Ancient Times: - The earliest known use of dental evidence in legal matters dates back to the ancient Roman era. In 49 BC, Agrippina, the mother of Roman Emperor Nero, identified her rival Lollia Paulina's disembodied head by examining her distinctive dental features.

Middle Ages: - In the Middle Ages, dental evidence was occasionally used in identification processes. For example, in 1477; the body of Charles the Bold, duke of Burgundy, was identified by his missing upper teeth, which he had lost in a previous battle.

19th Century: - The foundations of modern forensic odontology were laid in the 19th Century, In 1897 Dr. Oscar Amoedo Valdes, a Cuban dentist, published a book titled "L'Art Dentaire en Medecine Legale" (The Dental Art in Forensic medicine); which is considered as the first comprehensive text on Forensic Odontology.

20th Century: - Forensic Odontology gained significant recognition in the 20th Century, particularly after several high-profile cases. In 1932, the identification of the kidnapper & murderer of the Lindbergh baby was aided by dental evidences. During World War II, dental records were used to identify the remains of Adolf Hitler & Eva Braun. In 1979, the 'American Board of Forensic Odontology (ABFO) was established to develop standards & guidelines for the practice of Forensic Odontology. In 1970s, the development of computer-aided identification systems, such as- National Crime Information Center (NCIC) in the United States, facilitated the storage & comparison of dental records for identification purposes. In 1990s, the introduction of digital radiography & digital photography revolutionized dental imaging, enabling more accurate & efficient analysis of dental evidences.

21st Century: - Advancements in 3D imaging, Computer aided design/Computer aided manufacturing (CAD/CAM) & biometric technologies have further enhanced the capabilities of dental profiling. The use of intraoral scanners & 3D imaging has allowed for precise data acquisition & virtual treatment planning. Biometric dental identification techniques, such as- Tooth print analysis, Bite mark analysis & Lip print analysis (Cheiloscopy) have gained prominence. Genetic profiling & DNA analysis from dental pulp & root canal remnants have emerged as powerful tools for identification & ancestry determination.

Contemporary Developments: - Ongoing research focuses on refining dental age estimation techniques, facial reconstruction methods, & the integration of emerging technologies like- Artificial Intelligence & Machine Learning in dental profiling. International collaborations & the establishment of professional organizations, such as- International Organization for Forensic Odonto-Stomatology (IOFOS), have facilitated the exchange of knowledge & best practices in the field.

III. Dental Profiling In Forensic Odontology

Dental Profiling is a specialized technique within the field of forensic odontology that involves the analysis & interpretation of dental characteristics to establish individual identities. It plays a crucial role in victim identification, criminal investigations & medicolegal cases. Here's a detailed overview of dental profiling;

Dental Characteristics: - Teeth are highly resistant to decomposition & can withstand extreme environmental conditions, making them valuable sources of identification evidence. Dental characteristics, such as- tooth morphology, restorations, anomalies, & pathologies are unique to each individual & can be used for identification purposes.

Dental Records Comparison: - Dental profiling often involves comparing ante-mortem (before death) dental records with post-mortem (after death) findings. Ante-mortem records may include- dental charts, radiographs, treatment notes, & photographs provided by dentists or, obtained from dental clinics. Post-mortem records are collected during the forensic dental examination of the deceased individual. The comparison of ante-mortem & post-mortem records helps establish a positive identification or, exclude potential matches.

Radiographic Analysis: - Dental radiographs, such as- bitewing, periapical, & panoramic radiographs provide detailed information about tooth morphology, restorations & bony structures. Comparison of ante-mortem & post-mortem radiographs is a reliable method for identification, as radiographic features are unique & remain stable over time. Advanced imaging techniques, such as- Cone beam computed tomography (CBCT), offer 3D visualization & enhance the accuracy of radiographic analysis.

Dental Restorations & Anomalies: - Dental restorations including- fillings, crowns, bridges & implants can provide valuable identification evidence. The type, location, & material of restorations are

recorded in dental charts & can be compared with post-mortem findings. Dental anomalies, such as- missing teeth, supernumerary teeth, rotated or, tilted teeth & developmental defects can also aid in identification.

Dental Age Estimation: - Dental profiling techniques can estimate the age of an individual based on the development & eruption of teeth, as well as age-related changes in dental structures. Dental age estimation is particularly useful in cases involving unidentified juvenile remains or, in determining the legal age of an individual. Various methods, such as the Demirjian method, Radiographic method of Kvaal, Gustafson's methods are employed for dental age estimation.

Bite Mark Analysis: - Bite mark analysis involves the comparison of bite patterns found on victims or, objects with the dental characteristics of suspected individuals. Dental impressions, photographs, & overlays are used to analyze & compare bite marks. While bite mark evidence has been controversial due to its subjectivity & potential for misinterpretation, advancements in 3D imaging & digital analysis have improved its reliability.

Cheiloscopy & Rugoscopy: - Cheiloscopy involves the study of lip prints, which are unique patterns formed by the grooves & wrinkles present on the lips. Rugoscopy focuses on the analysis of palatal rugae, the irregular ridges on the roof of the mouth. Both Cheiloscopy & Rugoscopy can provide additional identification evidence, particularly in cases where dental evidence is limited or, unavailable.

DNA Analysis: - Dental pulp & root canal remnants can serve as sources of DNA for identification purposes. DNA extraction & analysis techniques have advanced significantly, allowing for the successful retrieval of genetic material from dental tissues. Dental DNA Analysis is particularly valuable in cases where conventional dental identification methods are inconclusive or, when ante-mortem records are unavailable.

Facial Reconstruction: - Dental profiling data can contribute to forensic facial reconstruction, which involves recreating the facial features of an unidentified individual based on their skeletal remains. Dental information, such as- the position & alignment of teeth, jaw dimensions & occlusal relationship guides the reconstruction process. Facial reconstruction can aid in public recognition & lead to the identification of missing persons.

Standardization & Quality Assurance: - Dental profiling relies on standardized protocols, terminology & reporting formats to ensure consistency & reliability. Professional organizations, such as- American Board of Forensic Odontology (ABFO) & the International Organization for Forensic Odonto-stomatology (IOFOS) provide guidelines & certification programs for Forensic Odontologists. Quality assurance measures, including peer review, proficiency testing & validation studies are essential to maintain the integrity & credibility of dental profiling evidence.
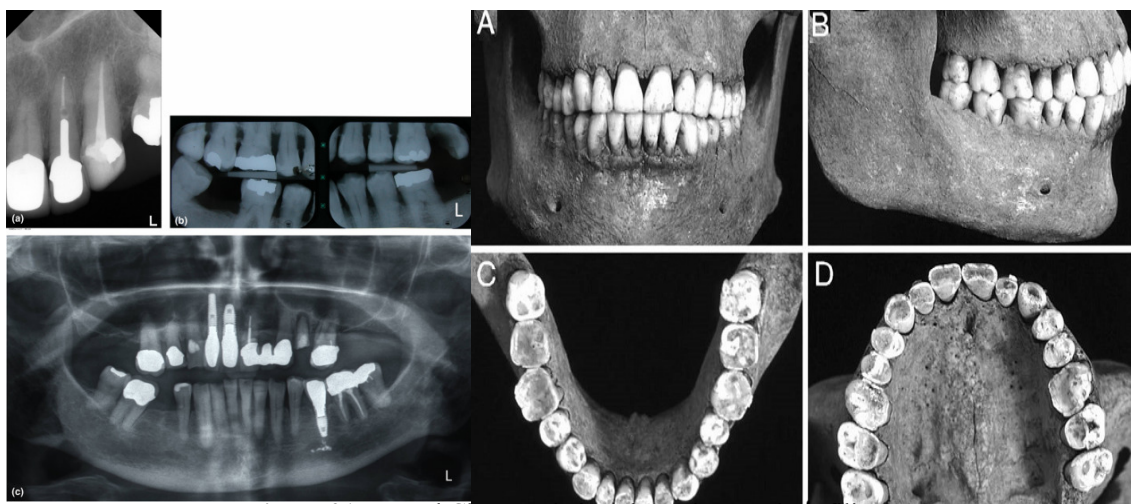

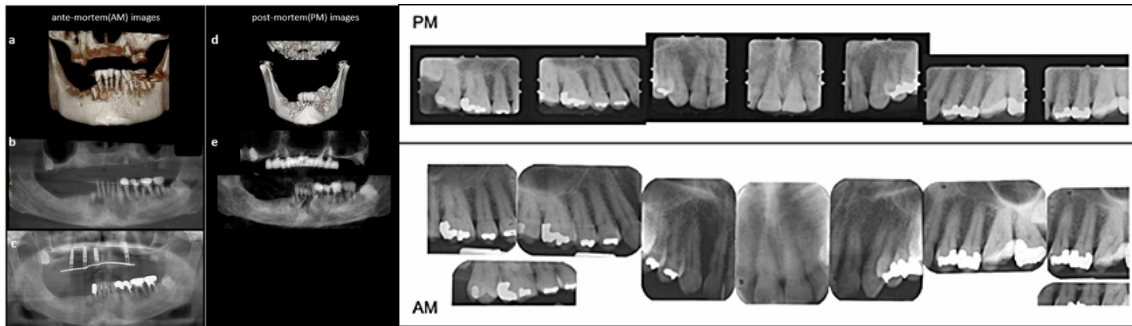**Figure 01:** Dental Characteristics Through Dental Profiling

Figure 02: Dental Records Comparison Through Dental Profiling (Cbct, Iopa Shows Dental Records After Ante-Mortem & Post-Mortem)
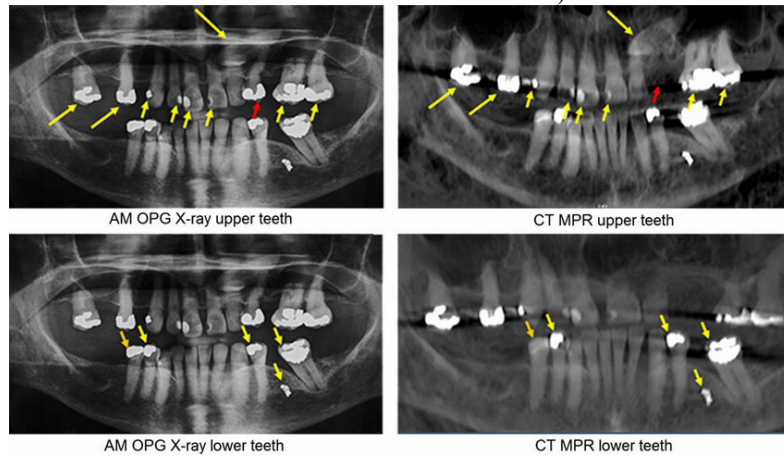

Figure 03: Radiographic Analysis Through Dental Profiling

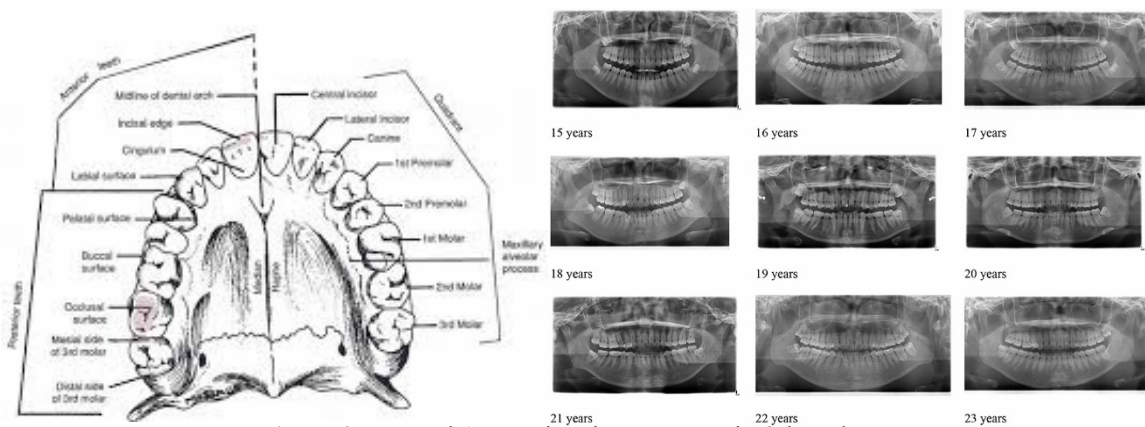**Figure 04:** Opg Shows Multiple Radiographic Anomalies

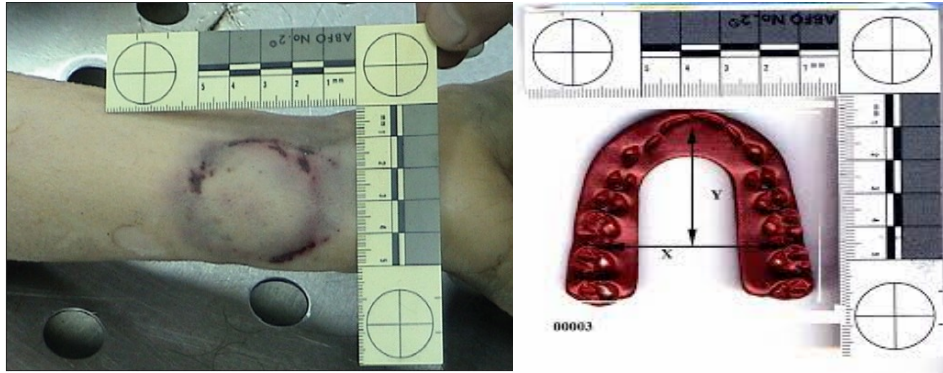**Figure 05:** Dental Age Estimation In Forensic Odontology

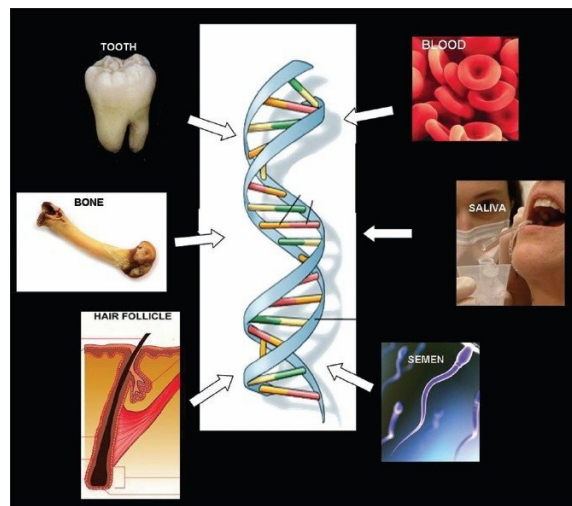**Figure 06:** Bite Mark Analysis In Forensic Odontology

Figure 07: Dna Analysis In Forensic Odontology

Figure 08: Facial Reconstruction In Forensic Odontology
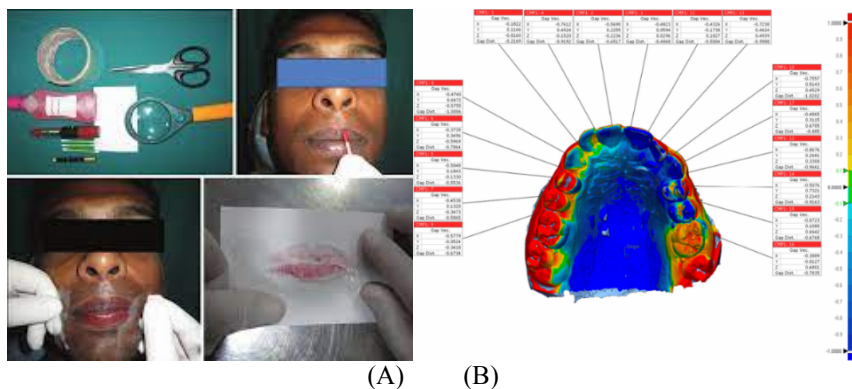

(A)   (B)

Figure 09: Cheiloscopy & Rugoscopy In Forensic Odontology
(A)   Cheiloscopy (Lip Print Examination & Analysis)

(B)   Rugoscopy (Palatal Rugae Examination & Analysis)

Figure 10: Standardization & Quality Assurance

Age Estimation & Dental Profiling

When the Ante-mortem records aren't available and no clues to the possible identity exist, a Post mortem (after death); dental profile is completed by the forensic dentist suggesting characteristic of the individual likely to narrow the search for the ante-mortem materials.

There are total of 3 steps in dental profiling:
1. Identifying ethnic origin from teeth.
2. Sex determination.
3. Age estimation from dentition.

Sex determination can be done by using various cranio-facial morphological parameters.

	Features	Male	Female
1.	Size/Architecture of Skull Morphology	Big/Rugged	Small/Smooth
2.	Frontal Eminence	Small	Large
3.	Forehead	Sloping	Vertical
4.	Supra-Orbital Ridges	Medium to Large	Small to Medium
5.	Palate	Large & 'U'- shaped	Small & 'Parabolic' - shaped
6.	Glabella	Moderate to marked curve	Flat to slight curve
7.	Orbits	Squared, Low, Rounded margins of orbit	Rounded, High, Sharp margins of orbit
8.	Zygomatic Arch	Extended	Normal
9.	Occipital Area	Marked muscle lines	Muscle lines not marked
10.	Mastoid Process	Medium to Large	Small to Medium
11.	Occipital condyles	Larger	Smaller
12.	Glenoid Fossa	Deep	Swallow
13.	Foramen Magnum	Large & Long	Round & Small
14.	General Mandibular Features	Large & Broad	Small & Narrow
15.	Condyles	'Larger'- in shape	'Smaller'- in shape
16.	Ramus	Broad ascending ramus	Narrow ascending ramus
17.	Shape of Chin	'Square'- shaped	'Rounded/Pointed'- shaped
18.	Gonial Height	Less Obtuse	More Obtuse
19.	Flaring	Flared up	Doesn't flared up
20.	Body Height	Presence of high symphysis	Presence of low symphysis

Dental age estimation using the dentition may be mainly grouped into '3'-phases;
❖ In pre-natal, neo-natal & early post-natal stage.
❖ In children & adolescent.
• Tooth Calcification Stages.
• Schour & Massler's Method.
• Demirjian's Method.
• Value of 3rd Molars in age estimation.
❖ In adults.
• Gustafson's Method.
• Dentin Translucency.
• Incremental line of Cementum.
• Biochemical Methods.
➢ Amino Acid Racemisation.
➢ Age estimation of C^{14} levels.

• Radiographic Method of Kvaal.

There are so many methods till date for age estimation & dental profiling in forensic odontology but the important methods for age estimation are- Demirjian's Method, Gustafson's Method & Radiographic Method of Kvaal.

Demirjian's Method: This method is mainly used to detect mostly in cases of children, adolescent & young adults. This method is mostly done on the lower left region of jaw (3rd Quadrant) for better assessment. This method is categorized mainly into '8'-stages from "A   H".

A – Mineralized Cusp tips; not yet coalesced.
B – Mineralized Cusps united.
C – The Crown is approximately half-formed.
D – Crown Formation is completed to DEJ.
E – Root Formation begins.
F – Root Length at least as great as the Crown Length.
G – Parallel Root walls with open apices.
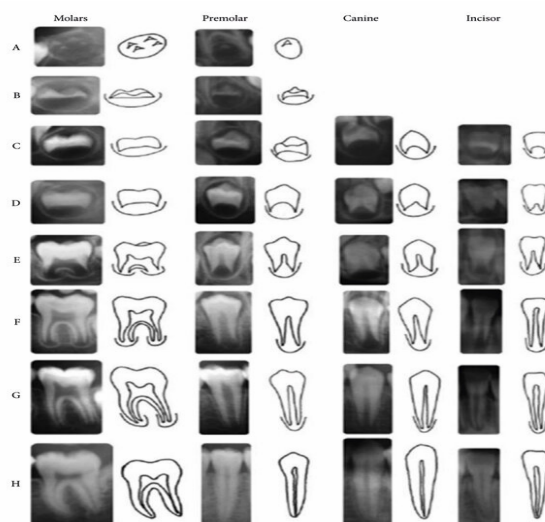H – Apices are closed completely.

Figure 11: Demirjian's Method Of Age Estimation

Gustafson's Method: This method was developed by- Gosta Gustafson (1950). This method is mainly used to determine age estimation for adults. This method analysis is done based on morphological & histological- changes of the teeth. The assessed regressive changes include;
❖A – Amount of Occlusal Attrition.
❖S – Coronal Secondary Dentin Deposition.
❖P – Loss of Periodontal Attachment.
❖C – Cementum Apposition at the Root Apex.
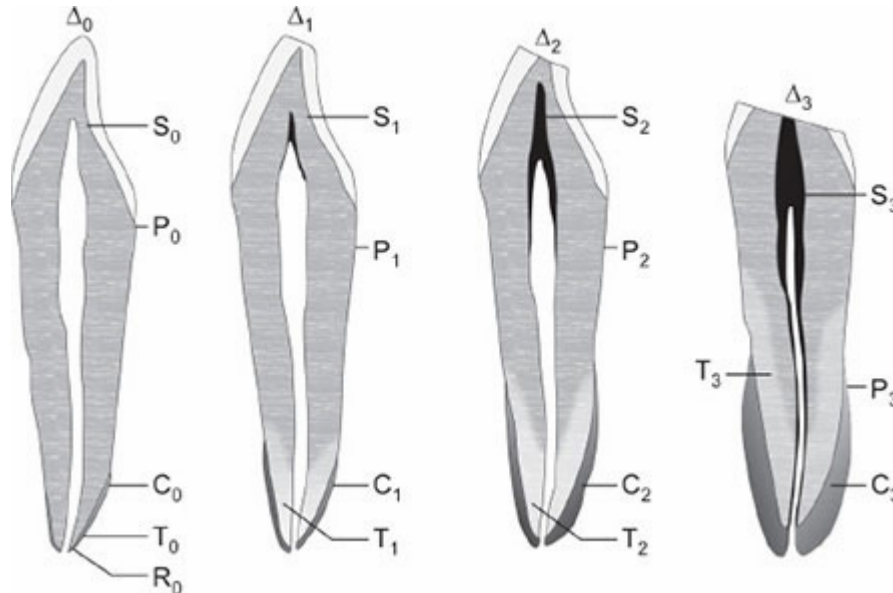❖R – Root Resorption at the Apex.
❖T – Dentin Translucency.

Figure 12: Gustafson's Method Of Age Estimation

Radiographic Method of Kvaal: Kvaal & it's associates developed a method that used pulp size measurements of '6'- teeth; 3 in maxillary arch & 3 in mandibular arch.

In Maxillary arch, teeth used for analysis are – Central Incisor, Lateral Incisor & 2nd Pre-molar & In Mandibular arch, teeth used for analysis are – Lateral Incisor, Canine & 1st Pre-molar. Measurements include;
❖Pulp-Root Length (P)
❖Pulp-Tooth Length (R)
❖Tooth-Root Length (T)
❖Pulp-Root Width at CEJ (A)
❖Pulp-Root Width at Mid-Root Level (C)
❖Pulp-Root Width at Mid-Root Level between A & C (B)
❖(M) – Mean Values of all ratios excluding T.
❖(W) – Mean Values of width ratios between B & C.
❖(L) – Mean Values of Length ratios between P & R.

Age is estimated by;

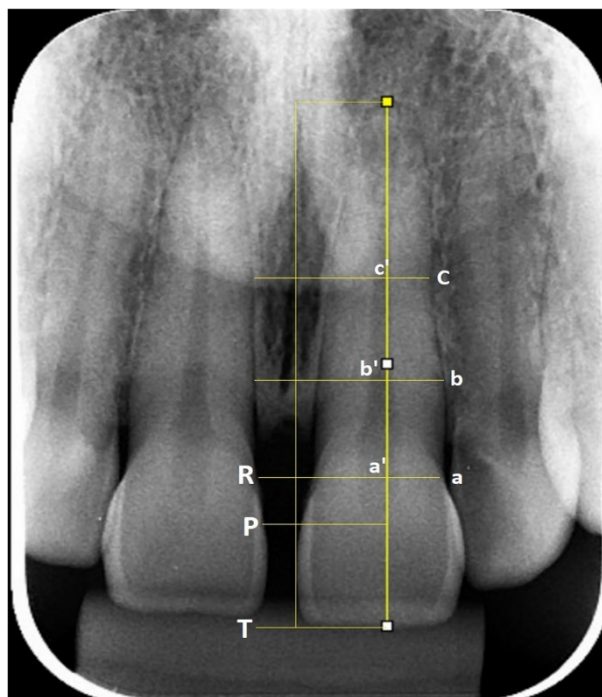**Figure 13:** Radiographic Method Of Kvaal Of Age Estimation

Bitemarks & Dental Profiling

A mark caused by teeth either alone or, in combination with other mouth parts. Mainly, this bitemarks are referred as – **"Dental Fingerprints"**. Bitemarks can be of 2 types; Animal Bite & Human Bite.

Human Bite is mainly – Broad, 'U'- shaped & Circular/Oval.

Animal Bite is mainly – Narrow in anterior aspect, Elongated, & 'V'- shaped.

Usually Sites;

❖In Females: On breast, legs (Mostly found in Sexual Assault cases).

❖In Males: Fingers, arms & shoulders (Mostly observed during Fight).

❖In Children: Genitals, oral & paraoral regions (Mostly found in Child Abuse cases).

Typical Presentation;

A representative human bite is described as- 'Elliptical/Circular Injury' that records the specific characteristics of teeth. The diameter of injury typically ranges from 25-40 mm.

Variations – A central ecchymotic area/'Suck mark' surrounded by radiating linear abrasions resembling 'Sunburst' found usually after sexually oriented crime.

Imprint of the inner surface of teeth against the skin is called – **"Drag Marking"**.

❖Double Bite marks can be seen when two bites are done quickly in the same location on the skin.

❖Partial Bite marks can be seen in situations when the victim moved during the bite.

Class Features:
- Incisors are 'Rectangular'- shaped.
- Canines are 'Triangular'- shaped.
- Premolars & Molars are 'Spherical/Point'- shaped.
- Individual features involve: Fractures, Rotations, Spacing.

Classification of Bite Marks:

1. **Cameron's Classification –**
- The agents that produced the mark.
- The materials & substances that exhibited the marks.

2. **McDonald's Classification –**
- **Tooth-Pressure Marks:** By incisal edges of the anterior teeth-stable with minimal distortion.
- **Tongue-Pressure Marks:** Tongue Pressure on palatal surfaces of the teeth; palatal rugae causes the distortion of marks.
- **Tooth-Scrape Marks:** Caused due to irregularities in teeth due to fractures & restorations.
- **Complex Marks:** Combination of all of the above mentioned 3 types of marks.

3. **Webster's Classification –**
- **Type-I Marks:** Bites in chocolate which fracture easily with limited depth of penetration. Most Prominent are- Incisal edges of upper & lower anterior teeth.
- **Type-II Marks:** Good grip of material obtained by teeth & then, bitten piece is fractured from the main material.
- **Type-III Marks:** Bite Marks produced by biting through cheese.

Data Collection from Victim:
1. Visual Examination.
2. Photographs of the Bite-Marks.
3. Salivary Swabbing.
4. Impression of the Bite-Marks.
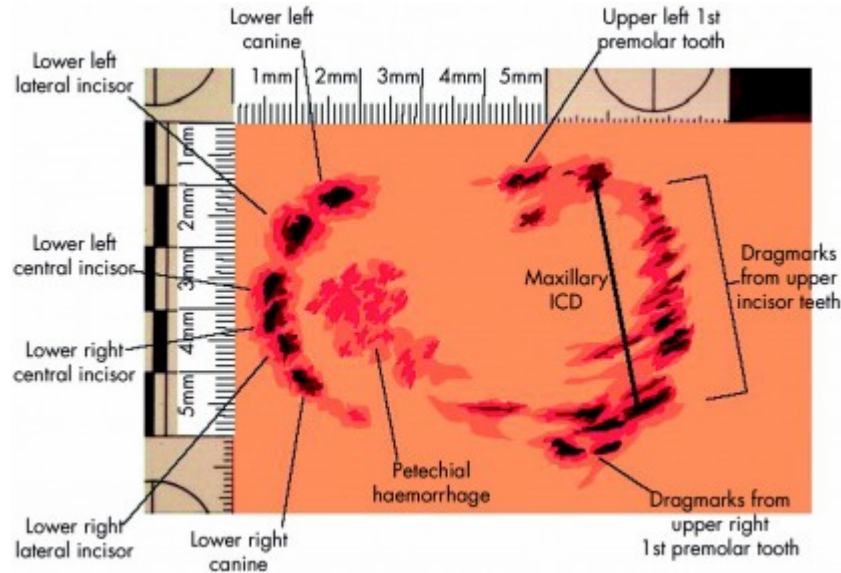5. Bite-Print Recording.
6. Tissue Samples.

Figure 14: Bite Mark Analysis

Lip Prints & Dental Profiling

Lip print is also known as- **"Cheiloscopy"**. It's a technique that deals with identifications of humans based on the lip traces. It can be observed as early as 6th week of IU-life & remain unchanged for the rest of one's life. Cheiloscopy have to be obtained within 24 hours of time of death to prevent the erroneous data would result from post-mortem alterations of lip.

- Closed Mouth Position – Well defined grooves.
- Open Mouth Position – Ill-defined & difficult to interpret.

Classification:

1. By Santos (1967) –
- Simple Wrinkles: Straight Line, Curved Line, Angled Line, 'Sine'-shaped Line.
- Compound Wrinkles: Bifurcated, Trifurcated, Anomalous.

2. By Suzuki & Tsuchihashi (1970) –
- Type-I: Clear-cut vertical grooves that mainly run across through the entire lip.
- Type-IA: Similar to type-I; but don't cover the entire lip.
- Type-II: Branched Grooves.
- Type-III: Intersected Grooves.
- Type-IV: Reticular Grooves.
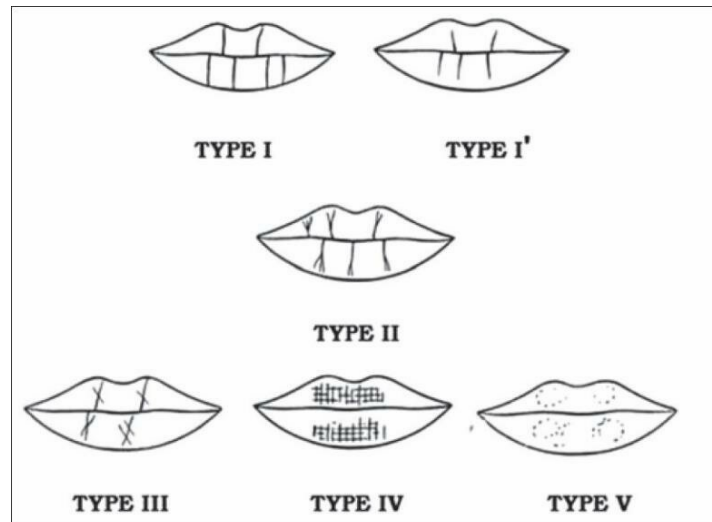- Type-V: Grooves that can't be morphologically differentiated.

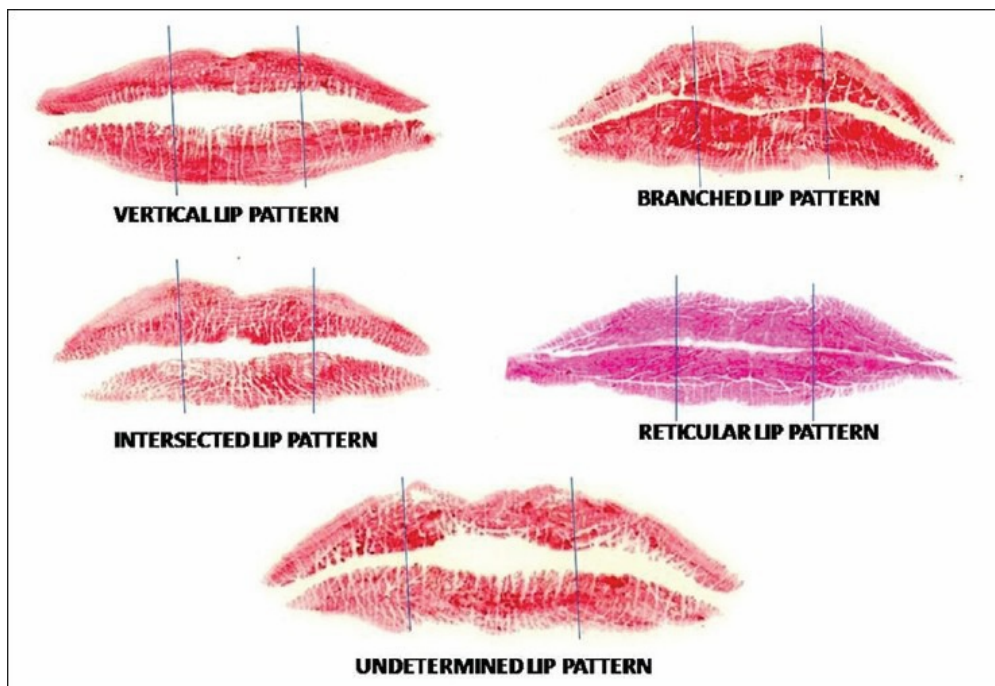**Figure 15:** Lip Print Classification By Suzuki & Tsuchihashi (1970)

Figure 16: Lip Print Analysis

IV. Recent Advancements In Dental Profiling Methods

1. **Digital Imaging & 3D Scanning –**
- **Cone Beam Computed Tomography (CBCT):** Provides high-resolution 3D images of dental structures, aiding in precise identification.
- **3D Printing:** Allows for the creation of accurate models of dental structures for analysis & presentation in the court.

2. **Artificial Intelligence & Machine Learning –**
- **Automated Identification System:** AI algorithms can analyze dental records & radiographs quickly, increasing the efficiency of matching dental profiles.
- **Pattern Recognition:** Machine learning models can identify unique patterns in dental work & tooth morphology that may be missed by the human eye.

3. Forensic DNA Analysis from Teeth –

- **DNA Extraction Techniques:** Improved methods for extracting DNA from the dentin & pulp of teeth have enhanced the ability to identify individuals, especially in degraded remains.

4. Age Estimation Techniques –

- **Cementum Annulations:** Counting incremental lines in the cementum of teeth to estimate age more accurately.
- **Translucency of Root Dentin:** Analyzing changes in root dentin translucency as a reliable indicator of age.

5. Bite Mark analysis –

- **Digital Analysis:** Use of advanced software for the digital analysis & comparison of bite marks, reducing subjective interpretation.
- **3D Reconstruction:** Reconstruction bite marks in 3D to improve accuracy in identifying suspects.

6. Dental Material Analysis –

- **Nanotechnology:** Analyzing dental restorations & materials at the nanoscale to determine their composition & potentially link them to specific dental practitioners or, regions.
- **Advanced Spectroscopy Techniques:** Using techniques like- Raman Spectroscopy to analyze the chemical composition of dental materials.

7. Interdisciplinary Approaches –

- **Integration with Other Forensic Sciences:** Combining dental profiling with other forensic methods, such as- Anthropology, Radiology, & Genetic Analysis to create a more comprehensive profile.
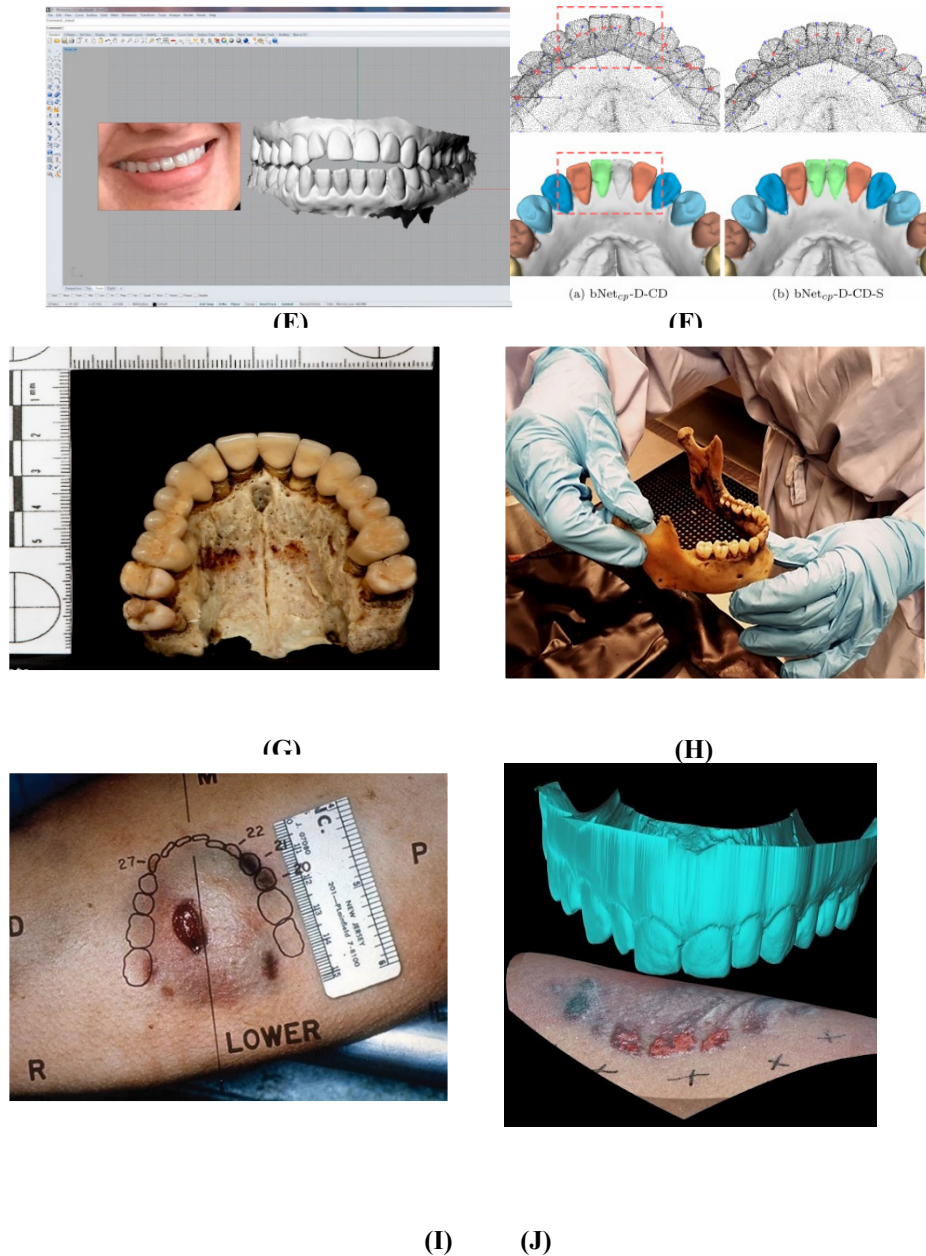

(A) **(B)**

(C) **(D)**

(E)

(a) bNet$_{cp}$-D-CD   (b) bNet$_{cp}$-D-CD-S
(F)

(G)

(H)

(I)   (J)
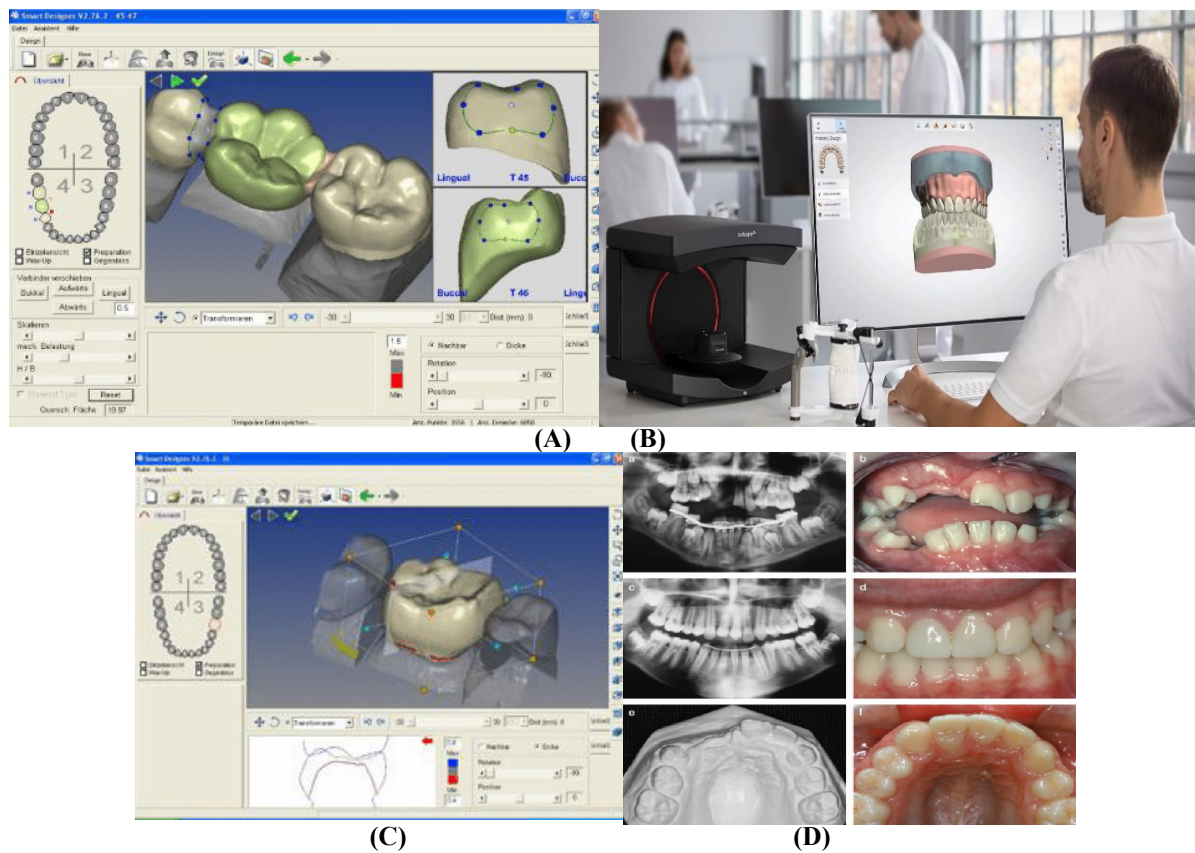
Figure 17: Recent Advancements In Dental Profiling Methods
(A, B, C, D, E, F, G, H, I, J)

V. Results

1. **Increased Identification Rates:** The use of CBCT, AI, & Improved DNA Extraction techniques has led to higher rates of accurate identification, even in challenging scenarios.
2. **Enhanced Accuracy:** The precision of digital imaging, machine learning models, & advanced material analysis has reduced the rate of false identifications & increased the reliability of forensic dental evidences.
3. **Improved Efficiency:** Automation & Digital tools have expedited the identification process, which is particularly crucial in large-scale disasters.
4. **Greater Legal Admissibility:** The use of advanced technologies & interdisciplinary approaches has strengthened the credibility of dental evidence in legal contexts. Detailed 3D models & Digital analyses provide clear, understandable evidence for courtroom presentations.

5. **Broadened Application:** Advanced techniques have expanded the application of forensic odontology to include more accurate age estimations, detailed bite mark analysis, & precise identification of dental materials.

VI. Conclusion

The integration of recent advancements in technology & interdisciplinary methods has transformed dental profiling in forensic odontology. These developments have made the identification process more accurate, efficient, & reliable, thereby; enhancing the overall effectiveness of forensic investigations. As technology continues to evolve, further improvements in dental profiling are anticipated, promising even greater contributions to the field of forensic science. Digital imaging techniques, such as- CBCT & 3D printing have revolutionized the visualization & analysis of dental structures. Enhanced DNA extraction methods from teeth have broadened the scope of forensic identification, particularly in cases involving degraded remains. As technology continues to evolve, the field of forensic odontology is expected to benefit from further innovations, promising even greater accuracy & efficiency in the identification process.

The ongoing research & development in this field underscore its crucial role in modern forensic science.

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