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**REVIEW ARTICLE**

# Dentistry as a Tool for Forensic Investigations: A Review

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## Abstract

Forensic dentistry is an emerging branch of dentistry which deals with application of dentistry in human identification. Confirming the identification of an individual after death is important for family, relatives and friends as it is related to their emotions and sorrow but it is also needed for legal purpose. As the dental structures remain preserved even under extreme environmental conditions so these can be helpful in identification process in various circumstances where identification from body of victim is not possible due to some reasons such as destruction and disfigurement of body. Dental tissues are also useful to evaluate age, gender and racial background of individual. Thus, forensic odontology has an integral contribution in forensic science for human identification and crime investigation. This paper gives overview of different methods used in forensic dentistry for human identification and crime investigation.

**Keywords:** Forensic dentistry, bite mark, teeth, DNA profiling, tongue print.

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## Introduction

Forensic dentistry is a subdivision of dental sciences which includes appropriate evaluation of evidences related to dentistry and their utilization for the purpose of justice. [1].

Commonly the individuals are identified using non dental methods such as visual identification by a family member, in person information, medical documents, footprints, fingerprints, and DNA analysis. Personal information includes height, age, body build and features related to hair and medical details such as scars, birthmarks, dental implants and prosthesis of individual [2]. Forensic dentistry is used for human identification in some circumstances such as mass disaster, fire explosion, road traffic accident, violent crime etc. In these situations, body of individual can be decomposed, destroyed or disfigured making his/her visual identification by a family member difficult and non-reliable [1, 3].

Human teeth are very rigid and sturdy tissue in the body. These are not affected from disintegration, burial, burns and other adverse environmental conditions. Human dentition pattern and some other oral structures are unique for every individual [4]. Therefore, these can be used for human identification. Dental identification of an individual is done on the basis of teeth, jaw, orofacial features using comparative dental identification method, and DNA fingerprints [5]. For identification of victims of natural catastrophe, ante mortem details of the unidentified individuals are compared with post mortem information obtained from dead individuals. In certain situations, ante mortem details are not available, so it is hard to exactly identify an individual and then DNA fingerprinting can help for the definitive identification of an individual [6].

Since late 1890s, this branch of dentistry has gradually evolved itself with its integral role in medico legal cases. A forensic professional helps legal authorities by evaluating evidences related to dentistry in various circumstances.

## Historical overview

1. There is well documented evidence that during 66 AD utilization of dentition for identification initiated with Agrippina and Lollia Pauline case [7].
2. In 1193, first forensic identification in India was carried out that was of Raja Jai Chand who was murdered, and his identification was done from his false teeth [8].
3. In 1758, Peter Halket who was died in French Indian war was identified from his artificial tooth [9].
4. In 1775, a dentist, Paul Revere, identified Dr. Joseph Waren who was died in battle for Breed's Hill in Boston by a denture he fabricated for him [10].
5. In year 1795, Prince louis XVII case utilized dental age

estimation method which is based on tooth development for confirmation of skeleton found in his coffin [11].

6. In 1814, first time dental evidence was presented in court case of Mrs. Janet Mc Alister in Scotland. The dental professional, Dr. James Alexander confirmed that denture of Mrs. Alister's fit only in one of the head in dissection room [12].
7. In 18th century, case of Dr. George Parkman, physician at Harvard University was solved with dental record evidences. His dental clinician, Dr. Nathan, done identification of Dr. Parkman's body from teeth of maxillary and mandibular denture which was fabricated three years ago. [13].
8. In 1865, the body of John Wilkes Booth was identified by his peculiar formation of jaws which was recorded by a dentist during his dental visit for restoration [14].
9. In 1870, Mrs. Robinson was murdered, and Mr. A. I. Robinson was suspected as murderer. A comparison was done based on bite marks and the suspect was recognized but was not at fault [15].
10. Victims of South Asian tsunami disaster were identified by various techniques like forensic dentistry, forensic pathology, fingerprint and DNA profiling [16, 17]
11. In 1977, Bodies of Hitler and his wife Eva Brauma were recognized from dental data with radiograph and prostheses [18]
12. The sack murder at Luton of Mrs. Manton in year 1943 and the body was identified by retained lower second molars and upper third molar [19,20].

## *Different methods used in forensic dentistry are:*

- Teeth as identification tool
- Chieloscopy
- Rugae print identification
- Tongue prints
- Denture identification method
- Bite mark analysis
- Facial reconstruction
- DNA profiling
- Comparison microscope

## *Teeth as identification tool*

Some special characters of human dentition differentiate it from other animals and make it unique [21].

**Teeth are used in following type of identification:**

- Identification of an individual
- Evaluation of gender and ethnicity
- Assessment of Habits and occupation
- Sex determination
- Age estimation

## *I. Identification of an individual*

Every individual have their own unique morphology and alignment of teeth. Comparative dental identification is method in which dental data from human remnants is compared with previous records for recognizing individual. Comparative dental identification needs maintenance of records of patients by every dentist [18]

- ***Evaluation of gender and ethnicity***

  It has been demonstrated that dental profiling helps in evaluating ethnicity, age and gender of an individual as some features of human teeth such as shovel shaped incisor, cusp of carabelli, four cusped mandibular molar, mandibular groove pattern and multicusped premolars show variation among different races. Some metric characteristics give clue regarding gender of individual which can be further confirmed with other evidences [18, 22].

  Sometimes dental restorations may indicate ethnicity of a person as restorative procedures followed in various countries may be unique and not employed in others. Based on cost of restorations, presence of high-priced restorations may provide information regarding social and economical level of a person. [23-25].

- ***Assessment of Habits and occupation***

  Some habits and occupations leave their mark on teeth such as tailors keep needle between their teeth, carpenters and electricians hold nails with their teeth, pipe smoking, tobacco chewing etc. Excessive wear of teeth has been reported in persons working in mining industry due to more exposure to olivine dust in the working area [23-25].

- ***Sex determination***

  Sex chromatin or Barr bodies present in pulpal tissue are used for sex determination. Enamel proteins also show variable pattern among genders. Two dissimilar AMEL genes, one present on X chromosome and other on Y chromosome found in men, while two similar AMEL genes located on X chromosome in females. [22, 26]

- ***Age estimation***

  **Age determination in prenatal, neonatal and early postnatal child**

  Neonatal lines are incremental growth lines indicating development during intrauterine and extrauterine environment and these are used to estimate age of neonates. Variations in rhythmic mineralization of enamel prisms are represented by Incremental lines of Retzius [27].

  Stack developed technique of age estimation by quantifying mineralized tooth structure. Developing teeth has weight of 60 mg at 6th month of intrauterine period, in newborn it is 0.5 gm and 1.8 gm in child after 6 months of birth [28].

## *Age estimation in children and adolescent*

***Schour and Massler's technique [29]***: They analyzed growth progress of deciduous and permanent dentition and established 21 chronological steps ranging from four months to twenty one years. This data is available in form of charts and American dental Association keeps it updated from time to time [29].

***Demirjian et al [30]***: They used seven mandibular teeth and described eight developmental stages (fig.1) of teeth. The stage of each tooth converted to scores using the tables outlined by Demirjian et al and scores are added to calculate the dental age [30]. Willem modified this method and evaluated the extent of development of left side teeth in mandibular arch. This method is more accurate than Demirjian's method [31].

***Moorees' Method***: This method established 14 stages (fig.2) for mineralization of single and multi-rooted teeth. Each stage is assigned with a certain age score and the age scores are averaged to calculate the dental age [32, 33].

***TCI- Benindra Method:*** This method relates chronological age and the dimensions of the dental pulp space. Pulp spaces in mandibular premolars and mandibular molars except third molars are observed as these are clearer than maxillary teeth. [34].

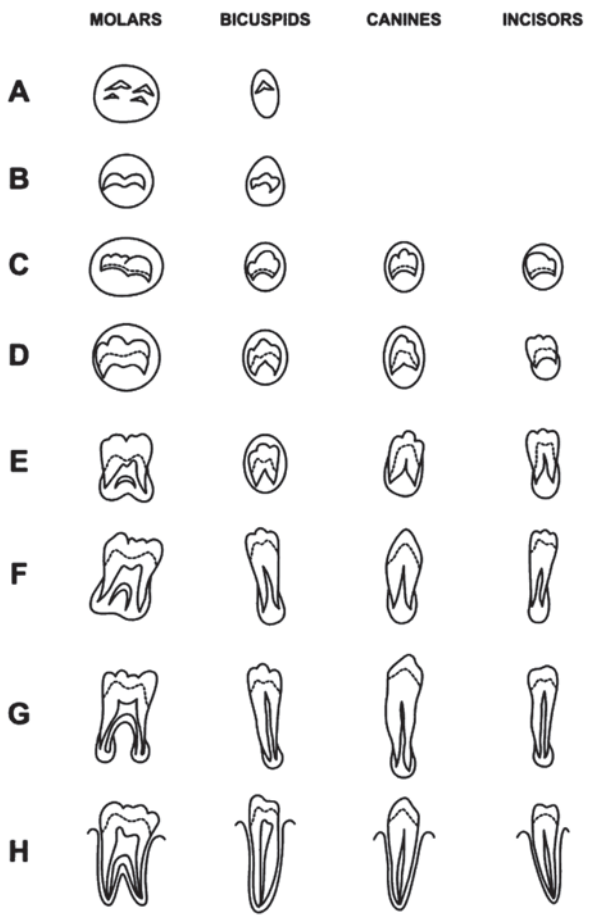



**Figure 1: Tooth development stages given by *Demirjian* et al [30].**

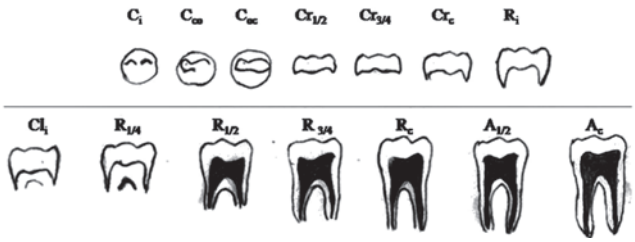



**Figure 2: Stages of development of multi rooted tooth. Stages: initial cusp formation (Ci), coalescence of cusp (Cco), cusp outline complete (Coc), crown half complete (Cr1/2), crown three-quarter complete (Cr 3/4), crown complete (Crc), initial root formation (Ri), initial cleft formation (Cli), root length quarter (R 1/4), root length half (R1/2), root length three-quarters (R 3/4), root length complete (Rc), apex half closed (A1/2), apical closure complete (Ac) [32,33].**

## Age estimation in adults

***Gustafson's Method:*** Gustafson [35] introduced age determination method and morphological and histological variations occurring with age in single rooted teeth (fig.3) form basis of this method. In this method, each criteria is scored as 0,1,2,3. All the scores are added to get total score (Y). Formula for age determination: Age=11.43 + 4.56 Y (Y is total score) [35].

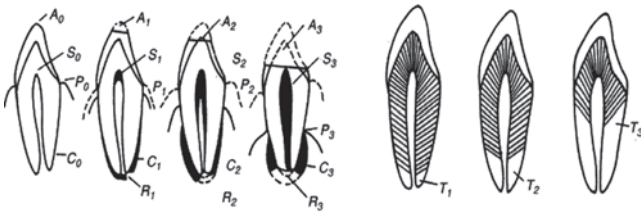


**Figure 3: Gustafson's method- Scoring for regressive age changes which are: Attrition (A), Secondary dentin (S), Periodontitis (P), cementum deposition (c), Root resorption (R), Transparency of dentin (T) [35].**

***Dalitz method*:** Dalitz [36] modified the Gustafson's method and used 5-point scoring system ranging from 0 to 4. Two criteria that were root resorption and secondary cementum were excluded for more precision and this technique also excluded the use of posterior teeth [36].

***Johanson [37]*** proposed changes in the Gustafson's method and established seven grades for the same six criteria. A section which is 0.25 mm thick was recommended for better evaluation of root transparency.

***Cameriere et al*** [38] gave Italian formulae for age estimation based on canines of both arches utilizing the pulp space and tooth area ratio (PTR). **Babshet et al** customized formula for age estimation in Indian population [39] using PTR. This formula is: 64.413-195.265 × PTR.

Aspartic acid is used for age estimation as it racemize faster than other amino acids. So, the level of aspartic acid in D-form increases with age in human enamel, dentin and cementum. This technique can be useful even 20 years after death [40]

**Spalding et al** [41] advocated that the radiocarbon quantity found in tooth enamel is a accurate age indicator.

- **Chieloscopy**

  It is a forensic analysis based on lip prints. Similar to fingerprints lip prints also provide useful forensic evidence in crime investigation [42]. Lip prints are patterns found on labial mucosa of lips created by wrinkles and grooves. In 1967, Santos [43] first time classified lip grooves into following types:

  - Straight line
  - Curved line
  - Angled line
  - Sine shaped line.

  Tsuchihashi et al [44] have suggested six types of groove patterns in the lips (fig.4). These are:

  - Type 1- Pattern with clear-cut vertical grooves running across whole lip
  - Type I'- Same as type I but the entire lip is not involved.
  - Type II – Pattern showing grooves with branches
  - Type III- With intersected grooves
  - Type IV- Showing reticular grooves
  - Type V - With grooves that are not morphologically differentiated [44].

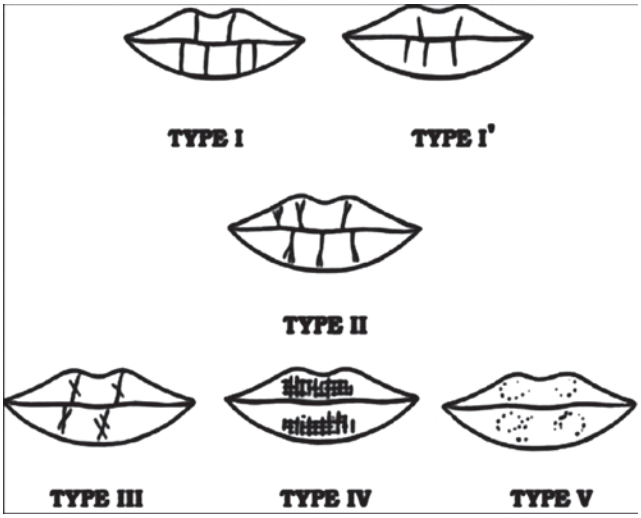
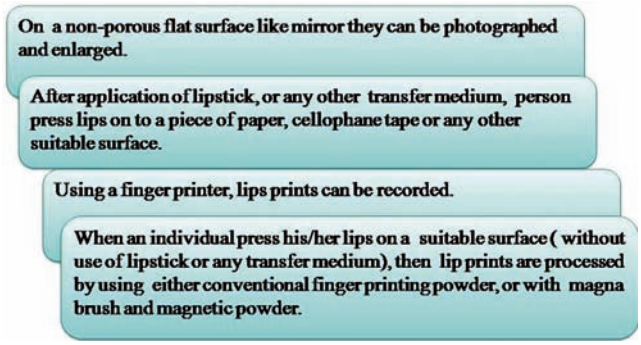



**Figure 4: Tsuchihashi et al classification [44]**

**Various methods are used for recording lip prints. These are [45]**




- **Rugae print identification**

  Rugoscopy is the analysis of palatal rugae pattern and is proposed by Trobo Hermosa in 1932 [46]. Sassouni [47] stated that each individual has different configuration of palate and there are no two alternate palate which are similar. Due to unique characteristic pattern, these could provide useful forensic evidence. Palatal rugae pattern can also help in differentiating gender and races [18].

Palatal rugae pattern has been classified by Thomas et al [48] as (fig.5):

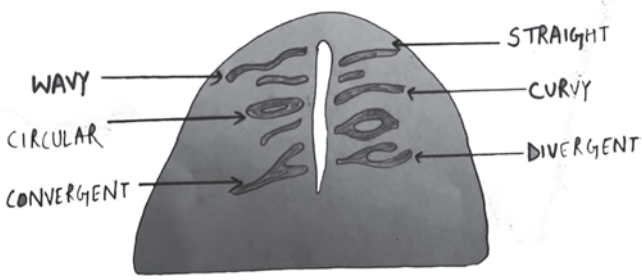



**Figure 5: Classification by Thomas et al [48]**

**Trobo [49]** classified palatal rugae into 2 types:

***Simple*** – Rugae with distinct shape. These are subdivided into A, B, C, D, E,F (fig.6)

***Compound*** These rugae are combination of two or more simple type rugae and classified as type X.

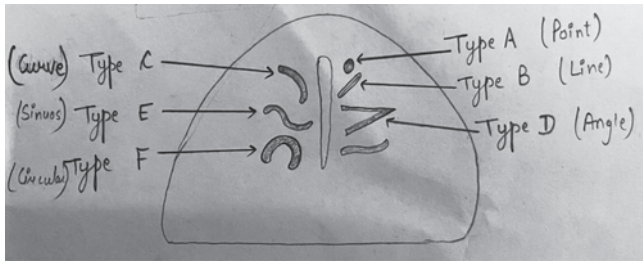



**Figure 6: Classification by Trobo [49]**

Procedure for analysis of palatal rugae pattern requires photographs and upper arch impressions, computer software programs, overlay print, formation of three-dimensional images of rugae through stereoscopy and stereophotogrammetry which is relatively more accurate [50].

Ohtani M et al [51] reported the shortcomings of palatal rugae use for identification in edentulous individuals. The misleading factors observed in their study were: no proper distinction of rugae, and alteration in height of palate.

- **Tongue prints**

  Each and every person has unique morphology of tongue. For the successful utilization of tongue prints in forensic investigation, the ante mortem details of tongue such as impression or photograph should be present. The lingual morphological records of tongue can be duplicated by utilizing alginate moulding method. The lingual impressions and photographs may comprise reliable methods for forensic investigation. [52]

## Methods of recording tongue prints

- Visual examination for evaluating color, surface texture of tongue, mobility and any other specific feature.
- Alginate impression followed by cast fabrication.
- Digital imaging of tongue.
- Histological examination [53]

Tongue biometric template can be made from three views that are lateral views, both right and left, and profile view. Extraction of tongue algorithm from collected points provides structured template for shape of tongue. Normalized histogram with Scale Invariant Feature Transform is used for analyzing surface texture of tongue. Templates obtained from both techniques are combined for doing matching [54].

- **Denture identification methods**

  In cases where victims have no teeth, only identifiable information can be obtained from dentures. Dentures having no markings are of minimum or no use in forensic science for identification. Labeling the dentures make them more reliable for forensic identification [55,56].

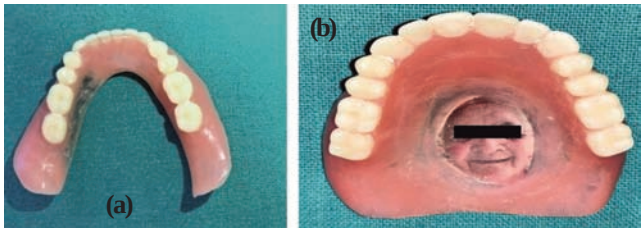



**Figure 7: (a) Denture with lead foil added for identification (b) Denture with photograph of patient**

Methods of denture labeling:

- Surface marking method
- Inclusion method

**Surface marking methods include**

- Scribing first letter of name and surname of individual on fitting surface of maxillary denture by using small round dental bur.
- Marking with embossed letters.
- Writing on denture surface using tape wrapped disposable blade to cut the patient's name or social security number on buccal surface of distobuccal flange.

These methods are simple and can be applied with ease but they wear off very easily.

**Inclusion methods include (fig.7)**

- Computer printed denture microlabelling system
- Metal identification bands
- Lead paper label
- Photograph
- Denture bar coding
- T bar
- Lenticular system
- Laser etching
- Radiofrequency identification tags

Inclusion methods are permanent, provide more reliable information but they could result in weakened denture, produce porosity, high priced and can be made by well trained clinicians in dental laboratories or in dental clinics with basic lab equipment's [57].

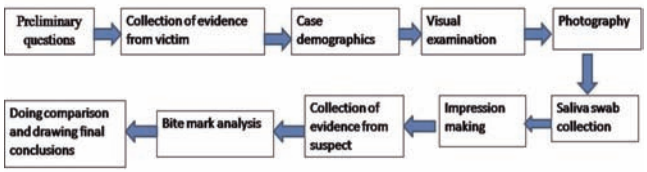
- **Bite mark analysis**

  It is mark created either by tooth alone or along with other mouth parts and may be present on different sites of victim's body including cheeks, legs, lips, buttocks or any other part of body. These may be observed on arm or face of attacker showing victim's defence against attacker [22].

**McDonald has classified bite marks on the basis of etiology as:**

- Tooth pressure marks
- Tongue pressure
- Tooth scrapes marks.

**Steps included in bite mark investigation are [18]:**




## Methods for bite mark analysis [58].

Following methods are used for bite mark analysis.

| Odontometric triangle method | Direct comparison method | Indirect comparison method |
|---|---|---|
| In this method two points A and B are marked on outermost convex points on the canine teeth. Point C is marked on center of two central incisors. A triangle is formed by joining these points and then lines AB, BC, CA and three angles of triangle are measured. This procedure is done for both arches and compared with bite marks on wax, apple or skin. | Models of suspect can be directly kept over the photograph of bite mark and model of bite mark. | This method makes use of transparent overlay which is then kept over the scaled photograph and comparison is done. |

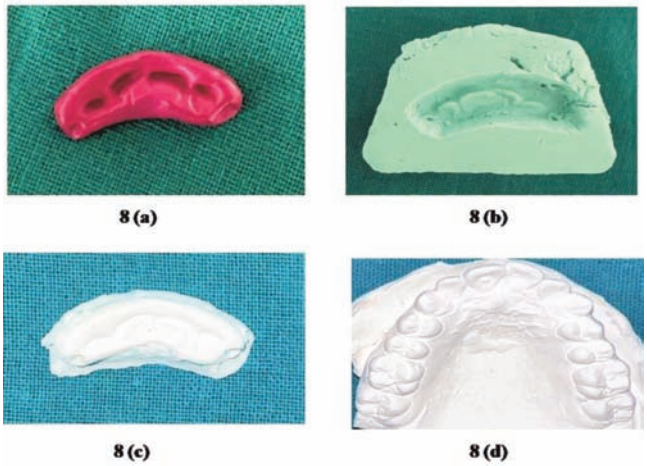



**Figure 8: (a) Bite mark on an object (b) Impression of bite mark (c) Positive replica of bite mark (d) Model of suspect's dentition**


**Figure 9: (a) Comparison by placing suspect's dentition model over bite mark (b) Comparison by placing suspect's dentition model over positive replica of bite mark.**

Human dentition may change over time, so bite marks lack specificity and durability [46].

- **Facial reconstruction**

  Kollman and Buchley [59], were first who worked on facial reconstruction. The same technique with modification was used today. Faces are specific to each and every individual in this world and are crucial for human identification. A computerized facial reconstruction system was generated for three-dimensional surface data acquisition of the human face. Computerized facial reconstruction makes use of a laser video camera interfaced with a computer or with CT scanning. It has been reported that three-dimensional CT imaging is more accurate as compared to imaging performed on CT slices and two-dimensional CT image reconstructions. Although exact photograph of face may not be constructed in this method, still it is excellent in identifying the individual [55, 60].

## Methods of facial reconstruction

### *Manual Method*

In the literature, Russian and American manual methods of face reconstruction have been explained. These were 2 D and 3 D methods making use of impression and clay modeling techniques. The impressions of skull were made, casts were prepared from these impressions and different landmark pins were applied over these casts. Certain facial characteristics were carved over the casts according to their anatomical positions. Then the models were painted, hair applied and photographs were taken (fig.10).

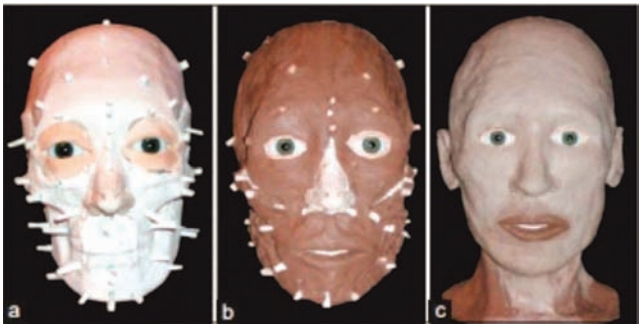



**Figure 10: Steps of facial reconstruction-(a) Replicated skull (b) Reconstruction of soft facial parts (c) Crude model of face [56].**

## Manual methods are simple, fast and easy to perform.

Limitations of these methods are: more time consumption, technique sensitive and costly.

## Computer aided reconstruction method

In this method 3D facial reconstruction depends on the principle of making a "face" onto the skull on the basis of application of mean tissue thicknesses for given anatomical landmarks.

## Advantages of this method

- High quality and resolution.
- It is totally noninvasive technique as it permits virtual handling, simulation, sectioning of bone in a virtual space hence protecting the original object.

### *Limitations*

- It is technique sensitive.
- Needs very well-trained personnel for interpretation of images achieved [61].

- ***DNA profiling***

  In 1985, Jeffreys et al [62] discovered radioactive molecular probes, able to recognize highly variable areas of DNA. Therefore, determining the specific patterns of each human being, which were referred as DNA fingerprints. The presently performed DNA profile tests are reliable and accepted as legal records in courts for paternity determination and individual identification. [15].

  Human teeth have capacity to withstand extreme environmental changes, so they represent an excellent source of DNA for investigations [11].

## Various methods of doing DNA fingerprint analysis are *[63,64]:*

- Polymerase chain reaction
- Restriction Fragment length polymorphism
- Short tandem repeat typing
- Single nucleotide polymorphism typing
- Analysis of mitochondrial DNA
- Analyzing Y chromosome
- X chromosome STR typing
- Automated STR genotyping

- ***Comparison microscope***

  Determination of sex on the basis of presence or absence of Y chromatin can be done under microscope [65]. Comparison with conventional microscope is more time consuming and depends on memory of observer when comparing two objects. Virtual Comparison Microscope (VCM) was developed to overcome these problems. It consists of two microscopes which are inter connected via an optical Bridge along with a view split window.

  This microscope allows analyzing specimens simultaneously and, in any direction [66].

## Virtual autopsy and Virdentopsy

Virtual autopsy is collection of radiographic dental information and comparing ante mortem and post mortem data. In this method jaws and dentition are examined without performing conventional dental autopsy.

Virdentopsy is another technique which involves identification using radiographic imaging, photographs, two and three-dimensional videography data and photogrammetry data. It also includes presence of remote forensic dentists from different areas without their physical presence on the site of investigation [67].

## Conclusion

Forensic dentistry is an emerging division of dentistry with a great scope of development. It has unique contribution in the law and justice for investigating various crime cases by providing reliable and acceptable evidences. There are many techniques available in forensic dentistry for identification, for determining age, gender and ethnicity of individual

As dentistry is useful in forensic science, therefore there is an increased need to make the dentists aware about the importance of forensic dentistry. Dentists should have a good knowledge about the available techniques in forensic dentistry and how these techniques can be used in identifying individuals and to investigate cases of abuse. Inclusion of forensic dentistry in undergraduate and postgraduate dental courses, conducting CDE programs and workshops could increase awareness and knowledge regarding the application of dentistry in forensic identification and investigation.

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|---|---|
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| ***Funding:*** | No external funding |
| ***Guarantor:*** | Prof. Sukhpal Kaur will act as guarantor of this article on behalf of all co-authors. |

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