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Advance Technologies in Forensic Odontology: A Narrative Review

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Abstract

Forensic odontology has become an important role for human identification, mostly when manual methods like fingerprint analysis, rugae examination, face recognition etc., are infeasible. Over the time, advance technologies have been rapidly increases in the field of forensics like digital scanning, digital imaging, advance algorithms, etc., by using these advance techniques, identification of unknown individual becomes easy. This narrative review includes the traditional and advance methods for identification purposes in conditions when the victim's body is totally unrecognizable. The paper highlights the evolution of the methods, effectiveness of the methods, comparison and applications. The advance technologies enhance more accuracy, more effectiveness in forensic evaluations. The review also identifies the obstacles including standardization of digital dental records in hospitals, and the need for more forensic database in various regions. The future scope and more advance technologies in forensic odontology are discussed.

Keywords: Forensic odontology, Human identification, digital technologies, digital imaging, digital scanning.

Introduction

Forensic Science has been defined as the application of scientific knowledge to aid in the investigation of crimes. One of the primary goals of Forensic Science is to identify unknown individuals. Forensic Science is used to aid in the investigation of crimes, the identification of victims of disasters, and in Medico-Legal Examinations. Forensic Science uses several methods to identify an individual. These include: Visual Recognition (e.g., Facial Features), Fingerprints, DNA Profiling and others. However, in some cases where there has been significant degradation of evidence (e.g., Advanced Decomposition, Incineration, Fragmentation, etc.), the previously mentioned identification methods may not be effective. It is at this point that Forensic Odontology becomes a reliable and scientifically valid method of Human Identification. forensic Odontology is the Application of Dental Knowledge to Legal Investigations to Aid in the Identification of Human Remains. Forensic Odontology involves the Examination of Dental Structures, Restorations and Tissues to Identify the Individual(s) being examined. Teeth are one of the hardest tissues in the human body and are extremely resistant to heat, chemicals and physical damage. As a result, teeth can survive in environments that would destroy all other Biological Identifiers.

In addition to this, the features of the teeth are unique to each person and are determined by genetics, diet, how well they brush their teeth, and the history of dental work, and therefore can be used as forensic identifiers. For years, forensic dentists have compared antemortem (pre-death) and postmortem (after death) dental records to identify an individual who has died. These records typically include dental charts, radiographs (x-rays), dental casts, and odontograms; all of which describe the shape, arrangement, fillings, missing teeth and other abnormalities present in the mouth. It is because of the specificity of the characteristics found in these records that forensic dentists are able to confirm the identity of a deceased person with a great deal of certainty. These methods have also been widely accepted as evidence in court cases and have played a critical role in forensic identification after disasters involving large numbers of people, such as when airplanes crash, buildings burn down or during natural disasters like earthquakes.

The success of using traditional forensic identification methods for the dead relies on having

accurate and complete dental records from before death. Unfortunately, there are parts of the world where there is little to no consistent recording of dental health of individuals. Therefore, it is necessary to use digital technology to help minimize the potential for errors and biases introduced into the comparison process between dental images taken pre-mortally and those taken post-mortally.

There have been tremendous advances in digital technology over the last twenty years, and all of them have impacted the field of forensic odontology. One of the major advances is in the type of x-ray technology used in dental offices. Conventional film-based radiography has been replaced by digital radiography. The advantages of digital radiography over film-based radiography include better image quality, less exposure to ionizing radiation and easier storage and transmission of images. Dental professionals now have access to digital records which can be shared rapidly among different facilities and geographic locations, thus facilitating a faster and more efficient investigation into a crime.

Additionally, new computer programs are available that enable forensic professionals to improve the visibility of subtle details of dental anatomy that might not be visible when viewing standard radiographs.

Another advancement in forensic dental technology is three dimensional (3D) imaging. A technology called cone beam computed tomography (CBCT) offers the ability to view dental and facial structures in three dimensions, and as such, eliminates many of the problems associated with two-dimensional (2D) imaging, i.e., magnification and superimposition.

Recent developments in Forensic Odontology include the introduction of Artificial Intelligence (AI) and Machine Learning (ML), which are used to develop automated and semi-automated methods of dental identification. Using these technologies, large databases of dental images and data can be analyzed to identify patterns and relationships that would not be observable through visual examination alone. While still in the early stages of development, AI-based systems have shown promise in many aspects of Forensic Odontology; they are being explored for use in dental age estimation, sex determination, and the automation of comparing dental records. The advantages of using AI-based systems include the reduction of human bias and an increase in consistent results, both of which represent important advancements in the field of forensic identification.

Forensic Odontologists have long recognized that the identification of individuals from their natural dentition is possible due to the inherent uniqueness of each person's teeth, however, recent advances in the identification of individuals using their dental implants and prosthetic devices have made them increasingly important as well. As modern dental implants are designed to be manufactured with unique features (i.e., shape, size, material composition, etc.), they can often be linked to a specific manufacturer based upon those features. Additionally, some dental implants contain a unique identifier or serial number that provides direct identification evidence. Prosthetic appliances such as crowns, bridges, and dentures also provide useful information for forensic purposes if properly documented.

Review of Literature

Conventional Dental Identification Techniques

Traditional dental identification has been the foundation of Forensic Odontology since its inception and has been widely discussed in the forensic literature. In early studies, the investigators were able to demonstrate the individuality of the dental morphology and dental restorations as reliable means of identification. Pretty & Sweet (2001) explains the methods that are used for human identification and accepted in court. In manual methods the identification is done by detailed study of every characteristic of teeth. Also radiographs of teeth results to be very important in identification using its external as well as internal parts. Previous studies shows that high accuracy rate of identification when the antemortem records are available. However, the reliability of manual methods compromised as compared to digital.

Digital Radiography and Electronic Dental Records

In the digital era, it has been seen that so analog data is shifted from digital data. It helps to analyze the dental radiographs and dental records more easily and in detail than analog data. As the electronic dental records store data more efficiently in the cases of fire accidents. Also, it has more improved the consistency and accessibility of data. However, still storing dental record in dental practices is a task.

Three-Dimensional Imaging and Superimposition

Uses of Three- dimensional imaging techniques in forensic odontology is increased and used in the production of high- resolution three-dimensional images of dental and maxillofacial structures with minimal radiation exposure. CBCT plays an important role in identification for creating 3 D images dental evidences. Superimposition of 3-D data to AM and PM records help to identify the similarities also it helps the examiner for findings.

Artificial Intelligence in Forensic Odontology

AI uses machine learning and other computed technologies to enhance the identification of dental records. Machine learning algorithms is used for dental age estimation, sex determination. Earlier researchers have examined that AI based models were used for dental age estimation, the results were more accurate than traditional manual methods.

AI system has ability of automating dental pattern recognition as mentioned in Ahmed et al (2024). This will help in reducing human error and minimizes the time efficiency in the cases of disaster victim identification. However, concern about algorithm clarity, data privacy will remain significant challenges.

Dental Implants and Prosthetic Identification

The dental implants have becoming recognized as reliable forensic identifier. Because it has specific implant details, designs and manufacturers. Based on manufacturers details and implant dental details will help to find the patient. There are many types of prosthetic appliances like dentures, crowns that provides valuable forensic evidences. Also, it is a need to label all the removable dentures with patient information so it will help the investigation team of forensics. This is underrated because of the inconsistency in storing information or documentation of implants and prosthetics.

Discussion

The advance technologies help traditional methods in forensic odontology that represents one of the most important advancements in this field. Digital imaging, 3D methods, and AI were increased the accuracy rate, efficiency, and objectivity in the field of forensic odontology to support traditional methods. However, there are several challenges to be found with respect to dental information collection, privacy of the data, ethical consideration regarding patients' information, dental digital data. To overcome these challenges, establishing regional dental databases and some standardized forensic protocols will help the forensic investigators to solve the cases.

Table 1. Comparison of Conventional and Advanced Dental Identification Methods

Method	Data Type	Advantages	Limitations
Conventional	Manual records,2D radiographs	Legally accepted, cost-effective	Examiner subjectivity
Advanced	Digital images, 3D datasets	High accuracy, reproducibility	High cost, technical expertise

Table 2. Advanced Technologies Used in Forensic Odontology

Technology	Application	Advantage
Digital radiography	Dental comparison	Easy storage & sharing
CBCT	3D anatomical analysis	High spatial accuracy

Technology	Application	Advantage
Superimposition	AM–PM comparison	Objective matching
Artificial intelligence	Pattern recognition	Reduced examiner bias
Dental biometrics	Automated identification	Rapid processing

Figures: Figure 1. Evolution of methods in forensic odontology.

Conventional Methods
(Dental Charting, 2D Radiographs, Casts)
↓
Digital Imaging
(Digital Radiographs, Panoramic Imaging)
↓
3D Technologies
(CBCT, 3D Reconstruction, Superimposition)
↓
Advanced Technologies
(AI, Machine Learning, Dental Biometrics)

Figure 2. Applications of methods used in forensic dental identification.

Advanced Technology
↓
Digital Dental
Records
↓
CBCT & 3D
Imaging
↓
AI & Pattern
Recognition
↓
Human Identification

Conclusion

Forensic odontology continuously help with identification of human remains, as it utilizes both traditional methods of identifying individuals through analysis of dental inspection and the application of advanced digital and artificial intelligence-based technologies to analyze data, and identifying the unknown individuals. This research also needs to be explored more by using new emerging technologies, ethically acceptable methodologies for implementing dental data also some standardized digital formats for dental records to continue tom advance odontology.

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