Literature Review

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Forensic dentistry as an interdisciplinary scientific field

Vladimir Panov

Department of Conservative Dentistry and Oral Pathology, Faculty of dental medicine, Medical University -Varna

Abstract

Forensic dentistry, or forensic odontology, is an interdisciplinary scientific field that applies dental knowledge to legal and judicial investigations. It plays a crucial role in identifying human remains, analysing dental and maxillofacial trauma, examining bite marks, and constructing biological profiles in criminal, civil, and mass-disaster contexts. Teeth and associated oral structures are highly durable and unique, making them reliable sources of evidence even under extreme conditions such as fire, prolonged decomposition, or mechanical stress. Moreover, dental tissues preserve DNA, especially mitochondrial DNA, when other biological materials are degraded.

Comparative dental identification, which involves the analysis of ante-mortem and post-mortem records, radiographs, and dental characteristics, remains the most reliable method for establishing identity. In mass disasters, forensic dental experts form part of multidisciplinary teams, complementing DNA analysis to ensure rapid and accurate identification. Bite mark analysis, although historically important, is increasingly scrutinized due to concerns about reproducibility and evidentiary validity, emphasizing the need for standardized, evidence-based approaches.

Age estimation in forensic dentistry employs morphological, histological, and biochemical methods, including tooth development, secondary dentin formation, root transparency, cementum annulation, and lead accumulation in dental tissues. Advances in digital technologies, enhance accuracy and reproducibility but require careful population-specific validation. Sex determination and population affiliation can also be inferred from dental and mandibular measurements, especially when combined with other anthropological data.

Ethical standards demand objectivity, methodological rigor, and transparency regarding limitations. As forensic odontology continues to integrate traditional and digital methods, it provides a scientifically robust and legally reliable framework for human identification, trauma assessment, and judicial investigations, ensuring its enduring importance in both forensic and humanitarian contexts.

Keywords: Forensic dental medicine, Identification of individuals, Age determination, Cementum annulation.

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Introduction

Forensic dentistry is an interdisciplinary scientific field that combines dentistry, forensic medicine, and legal sciences to provide scientifically sound expert opinions in court proceedings. It plays a central role in the identification of human remains, the assessment of maxillofacial trauma, and the analysis of dental evidence in criminal and civil cases (1,2). The main advantage of dental structures is their high resistance to extreme conditions, high temperatures, mechanical damage, and long periods of time, which makes them a reliable source of information even when other biological tissues are no longer available. Teeth are highly reliable sources of DNA in forensic contexts involving heat exposure. Although nuclear DNA is vulnerable, dentin and cementum, particularly their mitochondrial content, consistently provide viable genetic material. Teeth play a vital role in forensic identification due to their durability and exceptional ability to preserve DNA, even under extreme environmental stress. Among the hardest structures in the human body, dental tissues such as enamel, dentin, and cementum offer significant protection to genetic material thanks to their high mineral content and structural resilience (3-5).

In recent decades, forensic dentistry has become increasingly important due to the growing demands for rapid and accurate identification in disasters and accidents, as well as the requirements of modern criminal investigations. At the same time, the discipline faces critical scientific questions related to the evidential value of certain methods, such as bite mark analysis, and the need for standardized, reproducible approaches. DNA analysis has recently been introduced to forensic dentistry and is now frequently used in identifying individuals or determining the origin of certain tissues (6-10).

Aim

The objective of this study is to provide an analysis of the methods and applications of forensic dentistry, emphasizing its importance for judicial practice, as well as the ethical and legal aspects of expert activity.

Historical development

The first documented attempts to use dental characteristics for identification date back to antiquity, but the systematic scientific development of forensic dentistry began at the end of the 19th century with the publication of Oscar Amoedo's seminal work in 1897 (9). During the 20th century, especially during the world wars, dental identification became established as standard practice in the identification of deceased military personnel.

With the institutionalization of the discipline, professional organizations, specialized training programs, and international protocols were created, which significantly improved the quality, standardization, and evidentiary weight of forensic dental examinations (1).

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Methodological foundations of forensic dentistry

Comparative dental identification

Comparative dental identification is recognized as one of the most reliable methods for determining identity. It involves a detailed analysis of ante-mortem and post-mortem data, using clinical records, X-rays, orthopantomograms, smile photograph analysis, cheiloscopy, palatoscopy, and information about dental materials used. The uniqueness of the dental status in adults allows for high accuracy of identification, with the evidential value increasing in the presence of comprehensive preliminary documentation (11,12).

Identification in mass disasters

The forensic pathologist has always had a central role in the identification of the deceased in daily practice, in accidents, and in disasters involving hundreds or thousands of victims. In mass disasters, forensic dental medicine plays a key role in identification teams. This role has changed in recent years, as advances in forensic odontology, genetics, and anthropology have improved the chances of identifying victims beyond recognition. According to the Interpol DVI Guide, dental examination and DNA are the primary identifiers, which has given new emphasis to the role of the forensic pathologist as the leader of a multidisciplinary team of experts in disaster situations. Despite increased usage of DNA, dental identification has not been eliminated and remains a major contributor to identification (13,14).

Analysis of bite marks

The analysis of bite marks is used in cases of violence and sexual crimes. The process involves visual assessment, photographic documentation, and comparative analysis with the dental status of suspects. Pretty IA et al. revealed a lack of valid evidence to support many of the assumptions made by forensic dentists during bite mark comparisons. The authors call for a more scientific and evidence-based approach to forensic dental research (15). Mechanisms of production and appearance of bite mark injuries, collection of evidence, comparison techniques, and technical aids in the analysis of bite marks are described in detail in the literature (16).

Determination of biological profile

Age determination

Dental methods for age determination include morphological, histological, and biochemical indicators. In children and adolescents, stages of development, tooth eruption, and skeletal development are used, while in adults, regressive changes such as wear, quantitative secondary dentin, and root transparency are analyzed (17-19).

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In addition, some studies suggest that the accumulation of heavy metals, such as lead (Pb), in dental tissues correlates with age, which can be used as an additional forensic marker for approximate age in the absence of other data. Scientific analyses report that the concentration of Pb in dentin increases with age and can provide additional information for estimating the age of individuals, especially those over 50 years of age (20,21).

Another line of research uses cementum annulation analysis—alternating light and dark annual layers. This method has a high correlation with the actual age of individuals and is useful in young and middle-aged people (22,23). Although these alternative methods offer valuable additional information, they must be used carefully, taking into account population and environmental characteristics to ensure a reliable assessment.

In 2006, Cameriere R et al. presented a method for assessing chronological age based on the relationship between age and measurement of the open apices in teeth (24).

Table 1. Classical morphological and histological methods for age determination

Method	Target age group	Basic principle	Advantages	Limitations	Sources
Stages of tooth mineralization	Children and adolescents	Assessment of eruption and mineralization of temporary and permanent teeth	High accuracy in young individuals	Less reliable in juniors after the breakthrough	(18,19)
Tooth wear	Adults	The level of dental wear correlates with age.	Easy to visually assess	We are very dependent on diet and environmental factors.	(25)
Root transparency	Adults	Root transparency	Proven correlation with age	Requires X-ray or microscopic analysis	(25)

Table 2. Biochemical and new technologies for age determination

Method	Target age group	Basic principle	Advantages	Limitations	Sources
Pb concentration in teeth	Adults	Lead accumulation in dentin with advancing age	Additional biochemical marker useful in the absence of other data	Impact of environmental factors and exposure to lead	(20, 21)
Cementum annulation (cement rings)	Young and Adults	Number of light/dark annual layers in the root cement	High correlation with actual age, applicable to remains	Requires microscopic analysis, may be influenced by pathologies	(22, 23)
Digital 3D assessment	Children, adolescents, adults	Virtual models for development and wear analysis	High accuracy and reproducibility	Expensive equipment, need for training	(26, 27)

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Determining gender and population affiliation

Although sexual dimorphism in teeth is limited, its combination with other anthropological indicators can assist in constructing a biological profile. Measurements taken on the mandible proved useful in estimating the gender of the deceased. In cases of fragmentary or missing mandible, odontometrics can be used (28). Tooth crown dimensions are reasonably accurate predictors of sex and are useful adjuncts in sex assessment. The accuracy of mesiodistal (MD) variables alone is not high enough to warrant their exclusive use; higher accuracy is achieved when both MD and buccolingual (BL) dimensions are used concurrently (30).

Forensic dental examination in cases of trauma and violence

Dental and maxillofacial trauma analysis in the forensic context includes assessment of both living and deceased persons. It is required in all cases where human abuse is suspected and where signs of skeletal trauma are detected in human remains. Forensic dental medicine provides expert assessment in cases of maxillofacial trauma, including fractures, dental damage, and soft tissue lesions. The expert assessment includes analysis of the mechanism of trauma, the degree of damage, and the relationship between the events and the consequences (22,31).

Ethical, legal, and evidentiary aspects

Ethical standards require the forensic dental expert to be objective, independent, and to clearly communicate the limitations of their methods. Standardization and reproducibility of procedures are key to the evidentiary value of the expertise (32,33). Forensic dental determination remains a vital discipline in both judicial and humanitarian contexts, providing reliable evidence for human identification, age estimation, and trauma assessment. The resilience and individuality of dental tissues ensure their enduring importance, particularly in scenarios where other biometric markers are unavailable or compromised (34).

Discussion

Comparative dental identification remains the gold standard, but its effectiveness depends on the availability and quality of ante-mortem data (7,11). The lack of standardized dental records poses a serious challenge for experts.

The analysis of bite marks is one of the most debated methods. Systematic studies and forensic analyses highlight the high risk of false conclusions, which necessitates limiting its application and combining it with other evidence (17).

Dental age assessment continues to evolve through digital technologies, 3D imaging diagnostics, and machine learning algorithms, which show potential for improving accuracy but require validation across different populations (24). The digitization of forensic odontology and the automation of comparisons provide new opportunities but also raise questions about data security and legal admissibility (34).

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Conclusion

Forensic dentistry is an essential branch of forensic science that plays a critical role in human identification and the legal process. Due to the remarkable durability and individuality of dental structures, teeth often remain preserved even when other biological tissues are severely damaged or decomposed. This makes dental evidence one of the most reliable methods for identifying deceased individuals, particularly in cases involving trauma, fire, or advanced decomposition.

The comparative analysis of ante-mortem and post-mortem dental records forms the foundation of forensic dental practice. Unique dental characteristics, restorations, and treatment history allow specialists to establish identity with a high degree of scientific certainty. In addition, forensic dentistry contributes to age estimation and supports investigations in both criminal and civil cases, including mass disasters where rapid and accurate identification is essential.

Equally important is the ethical and professional responsibility of forensic dental experts. Their conclusions can significantly influence judicial outcomes, which requires strict adherence to scientific standards, objectivity, and clear communication. Through interdisciplinary collaboration and continuous advancement, forensic dentistry remains a vital and reliable component of modern forensic investigations.

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Corresponding author:

Vladimir Panov,
Department of Conservative Dentistry and Oral Pathology, Faculty of dental medicine, Medical University –Varna, Bulgaria
e-mail: vladimir.panov@mu-varna.bg

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