REVIEW

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The Role of Forensic Odontology in Modern Forensic Science: Applications, Responsibilities and Emerging Trends

Modern Adli Bilimlerde Adli Diş Hekimliğinin Rolü: Uygulamalar, Sorumluluklar ve Ortaya Çıkan Eğilimler

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Öz

Adli diş hekimliği, diş hekimliği bilimini hukuk sistemiyle birleştiren uzmanlaşmış bir alandır ve insan kimliğinin tespiti, yaş tayini, ısırık izi analizi ile istismar ve ihmal vakalarındaki ağız bulgularının değerlendirilmesinde hayati bir rol oynar. Dişler, dayanıklılıkları ve bozulmaya karşı dirençli yapıları sayesinde, özellikle diğer biyolojik materyallerin bulunamadığı durumlarda, adli soruşturmalarda kritik delil olarak sıkça kullanılır. Bu derleme, adli diş hekimliğinin uygulamaları, yöntemleri, yasal yükümlülükleri ve etik sorumluluklarını kapsamlı bir şekilde ele almaktadır. Dental kayıt karşılaştırması, radyografik değerlendirme ve diş dokularından DNA elde edilmesi gibi temel tekniklerin yanı sıra, hem yaşayan hem de ölmüş bireylerdeki ağız yaralanmalarının yorumlanması konularına da değinilmektedir. İncelemenin önemli bir bölümü, bu alanın yasal ve etik boyutlarına ayrılmıştır. Adli diş hekimleri çoğu zaman bilirkişi olarak görev yapmakta ve birçok ülkede çocuk istismarı ya da ihmali şüphesi içeren durumları bildirmekle yasal olarak yükümlüdür. Bu sorumluluk, özellikle hassas ve korunmasız gruplarda görülen travma veya kötü muameleye işaret eden klinik bulguların tanımlanmasını da kapsamaktadır. Ayrıca, derlemede ısırık izi analizi gibi bazı uygulamaların bilimsel güvenilirliğine ilişkin endişelere ve nesnel standartlar, şeffaf yöntemler ve temkinli yorumlara duyulan gereksinime dikkat çekilmektedir. Adli diş hekimliği adli bilimler açısından kritik öneme sahip olmasına rağmen, Türkiye dahil birçok ülkede hâlâ yeterince gelişmemiş bir alandır ve bağımsız bir uzmanlık dalı olarak resmi olarak tanınmamaktadır. Yapılandırılmış eğitim programlarının, akreditasyon yollarının ve kurumsal entegrasyonun eksikliği, bu alanda tutarlı ve güvenilir uygulamaların önünde önemli bir engel oluşturmaktadır. Gelecekte, bu disiplinin bilimsel geçerlilik, eğitim reformu ve yapay zeka ile dijital görüntüleme gibi yeni teknolojilerin entegrasyonunu öncelik haline getirmesi gerekmektedir. Disiplinler arası iş birliği ve etik temelli yaklaşımlar sayesinde, adli diş hekimliği modern adli bilimlere olan katkısını genişletme potansiyeline sahiptir.

Anahtar Kelimeler: Adli Diş Hekimliği, Adli Bilimler, İnsan Kimliklendirme, Yaş Tayini, Isırık İzi, Çocuk İstismarı

Abstract

Forensic odontology is a specialized field that integrates dental science with the legal system. It plays a vital role in human identification, age estimation, bite mark analysis, and the assessment of oral findings in cases of abuse and neglect. Teeth often serve as critical evidence in forensic investigations, especially when other biological materials are unavailable. This review provides a comprehensive overview of the applications, methodologies, legal obligations, and ethical responsibilities associated with forensic odontology. It addresses core techniques such as dental record comparison, radiographic evaluation, and DNA extraction from dental tissues, as well as the interpretation of oral injuries in both living and deceased individuals. A significant portion of the review is devoted to the legal and ethical dimensions of the field. Forensic odontologists frequently serve as expert witnesses and are legally mandated to report suspected cases of child abuse or neglect in many jurisdictions. This responsibility extends to the identification of clinical findings suggestive of trauma or mistreatment, particularly in vulnerable populations. The review also highlights concerns regarding the scientific reliability of certain practices, such as bite mark analysis, and the need for objective standards, transparent methodologies, and cautious interpretation. Despite its critical forensic value, forensic odontology remains underdeveloped in many countries, including Türkiye, where it is not formally recognized as a distinct specialty. The lack of structured training programs, accreditation pathways, and institutional integration poses a barrier to consistent and reliable practice. Moving forward, the discipline must prioritize scientific validation, educational reform, and the incorporation of emerging technologies such as artificial intelligence and digital imaging. Ultimately, strengthening scientific standards, establishing formal specialization pathways, and fostering interdisciplinary collaboration will enable forensic odontology to maximize its contribution to modern forensic science.

Keywords: Forensic Odontology, Forensic Sciences, Human Identification, Age Estimation, Bite Mark, Child Abuse

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INTRODUCTION

Forensic sciences represent a multidisciplinary approach to legal investigations, drawing on various scientific fields to uncover truth and support justice. Among these disciplines, forensic odontology plays a particularly crucial role in the identification of individuals and the analysis of dental evidence in both criminal and civil cases (1). Because teeth are highly durable and can resist decomposition, fire, and trauma, they provide valuable data in situations where other forms of identification may not be possible (2). The discipline operates at the intersection of dentistry and law, offering insights through dental record comparison, bite mark evaluation, and oral injury assessment (1,2).

Although the relevance of dental evidence in legal matters has been acknowledged for centuries, the field remained relatively underdeveloped until the 1960s, when formal education programs were introduced—most notably in the United States at the Armed Forces Institute of Pathology (3,4). These initiatives led to a significant increase in forensic dental cases, establishing the term "forensic odontology" within the dental community, law enforcement, legal professionals, and forensic specialists. Today, forensic odontologists assist legal authorities by examining dental findings in diverse contexts (3). Broadly, the field encompasses three main areas: civil or non-criminal investigations, criminal investigations, and academic research (3).

In recent decades, the role of forensic odontology in disaster victim identification (DVI) has expanded significantly, reflecting technological progress and the increasing scale of mass fatality incidents worldwide. According to INTERPOL and global surveys, dental methods contribute to the identification of up to 60% of victims in certain disaster contexts, particularly when visual recognition and fingerprinting are compromised (5). Events such as the 2004 Indian Ocean tsunami and the 2011 Great East Japan earthquake demonstrated the indispensability of dental evidence, with post-mortem dental profiling often serving as the sole reliable means of identification when other biological markers were absent or degraded (5). The efficiency of these operations relies heavily on standardized protocols, interoperable dental charting systems, and trained personnel—elements still inconsistently implemented worldwide. This global perspective underscores the urgent need to address methodological gaps, especially in jurisdictions where forensic odontology is not formally institutionalized, to ensure timely, accurate, and legally robust identifications in future disaster scenarios.

Given these developments, this review synthesizes current global practices, identifies persistent standardization gaps, and discusses how emerging technologies—such as artificial intelligence and digital imaging—can be integrated into forensic odontology to enhance its scientific validity and operational impact, with particular emphasis on countries like Türkiye, where formal recognition and structured training programs are lacking.

SCOPE AND METHODS OF FORENSIC ODONTOLOGY

Forensic odontology encompasses the examination and interpretation of dental evidence for legal purposes. It plays a key role in human identification, dental age estimation, bite mark analysis, and the assessment of oral injuries in both living and deceased individuals (6,7). At the intersection of dentistry and law, it supports investigations in criminal, civil, and disaster victim identification contexts (7–9).

Its objectives are achieved through various methods, including dental record comparison, radiographic analysis, DNA extraction from dental tissues for identification purposes, age estimation, and bite mark

Table 1. Comparative overview of key forensic odontology methods, highlighting their main advantages and disadvantages

Method	Advantages	Disadvantages
Dental Record Comparison	Unique dental patterns provide high specificity; Cost-effective; Widely accepted in courts as primary identifier when DNA/fingerprints are unavailable.	Requires high-quality and up-to-date ante-mortem records; Documentation practices vary across clinics; Incomplete or missing records reduce reliability.
Radiographic Methods	Non-invasive; Reveal root morphology, sinus anatomy, trabecular bone patterns; CBCT and digital imaging enhance accuracy with 3D visualization.	Dependent on availability and quality of ante-mortem images; Variability in imaging protocols and angles complicates comparisons; Post-mortem damage may obscure features.
DNA Extraction from Dental Tissues	Highly specific; Teeth resist decomposition, fire, and trauma, preserving viable DNA; Enables nuclear and mitochondrial DNA analysis; Useful in mass disasters.	Time-consuming and resource-intensive; Environmental degradation or contamination can reduce DNA yield; Requires specialized lab infrastructure.
Dental Age Estimation	Reliable in children and adolescents due to predictable tooth development; Multiple validated methods (Demirjian, Cameriere, London Atlas); Applicable in immigration, legal liability, and disaster cases.	Less precise in adults (wide confidence intervals); Influenced by nutrition, systemic disease, and ethnic variation; Some methods invasive (e.g., cementochronology).
Bite Mark Analysis	May link suspect to victim; Helpful in abuse or violent crime cases; Can serve as supportive or exclusionary evidence when used cautiously.	High subjectivity; Skin is elastic and patterns distort over time; Lack of reproducibility and standardized protocols; Weak scientific foundation—limited admissibility in courts.

analysis (10–12). The following sections describe each method in detail, outlining their scientific basis, procedural steps, and practical considerations. A comparative overview of the main forensic odontology methods, highlighting their advantages and disadvantages, is presented in Table 1.

Dental Record Comparison

One of the most fundamental techniques in forensic odontology is the comparison of ante-mortem and post-mortem dental records. This method relies on the unique characteristics of an individual's dentition, such as tooth shape and position, presence or absence of teeth, restorations, extractions, prostheses, and any pathological findings (13). Dental records may include clinical notes, photographs, study models, and treatment charts, all of which can be compared with the findings obtained during the forensic examination of unidentified remains (14). In cases where detailed ante-mortem documentation is available, even a few distinctive features—such as an unusual crown morphology or a rare type of prosthesis—can lead to a positive identification (15,16).

Published case reports illustrate how such distinctive features can decisively establish identity. In one case, an unidentified accident victim was identified when post-mortem dental charting matched ante-mortem records obtained from private clinics, revealing a unique combination of missing teeth and distinctive fixed prosthetic work (17). In another case, remains were identified by comparing a panoramic photograph of a patient's dental arch, taken nearly a decade earlier, with the post-mortem condition. The match included specific patterns of restorations and tooth alignment that were sufficiently distinctive to confirm the identity, despite minor discrepancies in written records (18).

Dental record comparison is particularly valuable in mass fatality incidents, where visual identification may be impossible due to severe trauma or decomposition (19). The accuracy and reliability of dental identification depend heavily on the quality and completeness of ante-mortem

documentation and the training of the forensic odontologist. In many jurisdictions, a match based on dental features is accepted as legally admissible evidence for establishing identity when other primary identifiers, such as DNA or fingerprints, are unavailable (20). Limitations include incomplete, outdated, or unavailable ante-mortem records and inconsistent documentation practices between dental providers, which may reduce the reliability of comparisons (19,20).

Radiographic Methods

Radiographic imaging plays a critical role in forensic odontology by enabling the non-invasive visualization and comparison of ante-mortem and post-mortem findings. Unlike general dental record comparison, which may involve various forms of documentation, radiographic methods focus specifically on imaging-based identification, taking advantage of the unique internal and structural characteristics of teeth and surrounding bone (14,21,22). Commonly used techniques include periapical, panoramic, and bitewing radiographs, which can reveal features such as root morphology, pulp chamber configuration, trabecular bone patterns, and sinus anatomy.

Case reports illustrate the decisive role of radiography in forensic identification. In one case, skeletal remains of an unidentified individual were examined using post-mortem periapical radiographs of mandibular molars. When compared with ante-mortem lateral skull radiographs, identical crown-root morphology and mandibular canal positioning were observed, leading to a conclusive identification (23). In another case, the charred remains of a victim from a vehicle fire were identified through the comparison of ante-mortem panoramic radiographs with post-mortem periapical images. Distinctive features such as root angulation, pulp chamber outline, and the shape of furcation areas matched exactly, despite the absence of any surviving soft tissue (24).

Advanced imaging techniques such as Cone Beam Computed Tomography (CBCT) have further enhanced forensic capabilities by providing three-dimensional visualization with high spatial resolution (25). CBCT allows volumetric reconstruction of maxillofacial structures, which can be digitally aligned to match ante-mortem images, minimizing errors from angulation differences (26). In addition, digital radiographic systems and image enhancement tools—such as superimposition techniques and 3D reconstructions—enable forensic odontologists to detect subtle morphological details with greater accuracy (27).

Despite these advances, radiographic methods remain dependent on the availability and quality of ante-mortem images. Variations in imaging angles, exposure settings, and equipment types can complicate comparisons, while severe post-mortem damage to hard tissues may obscure key features. The absence of standardized imaging protocols across dental practices also poses a challenge, potentially reducing the reliability of matches in legal contexts (25-27).

DNA Extraction from Dental Tissues

Teeth are among the most durable structures in the human body, capable of withstanding extreme conditions such as high temperatures, decomposition, and mechanical trauma. This resilience makes them an invaluable source of DNA in forensic investigations, particularly when soft tissues are no longer available for analysis (28). The pulp chamber, protected by enamel and dentin, often retains viable nuclear DNA even after extended post-mortem intervals. In cases of mass disasters, plane crashes, fires, or advanced decomposition, dental tissues may be the only remaining biological material suitable for genetic identification (29,30).

There are two main approaches to obtaining DNA from

teeth: accessing the pulp directly or grinding the tooth structure to extract DNA from dentin or cementum. The direct pulp access technique involves sectioning the tooth—often longitudinally—under sterile conditions to minimize contamination (30). Alternatively, the entire tooth or root segment may be cryogenically frozen and pulverized into a fine powder using liquid nitrogen, after which chemical and enzymatic digestion protocols are applied (31). While nuclear DNA provides the highest degree of individual specificity, mitochondrial DNA (mtDNA) is often used when nuclear DNA is degraded or absent. Since mtDNA is more stable and present in greater quantities per cell, it serves as a powerful tool for identification, particularly in older remains or compromised samples (32).

The extraction and analysis of DNA from dental tissues have applications far beyond post-mortem identification. Dental DNA can be used to resolve missing person cases, establish biological kinship in disputed paternity or maternity scenarios, and identify perpetrators in criminal investigations when teeth are recovered as trace evidence (e.g., in bite mark cases) (33). The integration of modern genetic techniques such as STR (Short Tandem Repeat) analysis, PCR (Polymerase Chain Reaction), and next-generation sequencing has further enhanced the accuracy, speed, and reliability of forensic DNA profiling from dental sources (33,34). As these molecular techniques continue to advance, dental tissues remain a cornerstone of forensic genetic identification—particularly in challenging forensic contexts where other biomaterials are not viable. Nevertheless, certain practical and technical limitations persist. DNA analysis from dental tissues may be affected by environmental degradation, contamination, or insufficient DNA quantity, particularly in highly compromised remains. Additionally, processing can be time-consuming and resource-intensive in large-scale incidents (30–33).

Dental Age Estimation

Dental age estimation is a fundamental component of forensic odontology, especially in legal contexts where determining whether an individual is a minor or adult is crucial. Unlike other biological indicators such as bone development, dental structures follow a relatively predictable and genetically regulated timeline, making them highly reliable—particularly in children and adolescents (35). Forensic age estimation based on dentition is widely used in both deceased and living individuals in situations such as mass disasters, undocumented immigration, asylum applications, and age-related criminal liability assessments (36,37).

A wide range of methods has been developed to estimate age based on dental development, and these are generally classified into two main categories: developmental methods (based on tooth formation and eruption) and degenerative methods (based on physiological aging changes) (36). Among the most widely applied developmental methods is the Demirjian method, which uses panoramic radiographs of the mandibular teeth (usually seven left permanent teeth) and assigns developmental stages to estimate age (36). Several modifications of this method have been proposed over time, including the Willems method, which adjusts Demirjian's scoring to better suit European populations (38), and the Haavikko and Moorrees methods, which offer alternative scoring systems for different tooth formation events (39,40).

In recent years, newer tools and models have emerged to improve precision and applicability across diverse populations. One such tool is the London Atlas of Human Tooth Development and Eruption, which provides visual references for dental formation and eruption stages from prenatal life to early adulthood (41). It is especially valued for its ease of use in clinical and field settings. Another frequently used method is the Cameriere method, which calculates dental age based on the open apices of

developing permanent teeth (42). The original Cameriere formula has since been adapted for multiple ethnic populations, leading to the creation of population-specific models such as the Cameriere-European formula, which offers more accurate age estimates by accounting for geographical and racial variations (35,43). Similarly, the Blenkin-Evans method, developed in Australia, uses the lower third molar development on orthopantomograms for legal age estimation, especially in late adolescence (44).

For adult individuals, where tooth development has been completed, age estimation relies on degenerative changes such as secondary dentin formation, cementum deposition, and root transparency. Techniques like Gustafson's criteria and Kvaal's radiographic method are used in this age group, though they tend to have broader confidence intervals and require high examiner expertise (45,46). Additionally, cementochronology—which involves counting annual incremental lines in dental cementum—has gained attention for its potential to provide accurate chronological age, though it is still considered a more invasive and technically demanding method (47).

With the increasing awareness of ethnic and regional differences in dental development, many recent studies have focused on creating population-specific reference datasets and formulas. Countries such as India, Brazil, Türkiye, and China have all published modified versions of existing methods or developed entirely new models to improve forensic accuracy within their populations (48–51). This evolution highlights a key trend in forensic odontology: the move toward localized, evidence-based standards rather than universal models. As imaging techniques, computational tools, and artificial intelligence (AI)-supported analysis continue to advance, dental age estimation remains a dynamic and essential component of forensic identification protocols worldwide. However, its accuracy can still be influenced by factors such as nutritional status, systemic diseases, and population-specific growth patterns. In adult cases, degenerative methods often yield wider confidence intervals and require substantial examiner expertise, while certain techniques—such as cementochronology—are invasive and may not be feasible in all forensic contexts (48–51).

Bite Mark Analysis

Bite mark analysis is one of the most well-known yet controversial applications of forensic odontology. It involves the examination, documentation, and interpretation of patterned injuries or impressions believed to have been caused by human dentition (52). Such marks are most commonly found in cases involving violent assaults, sexual abuse, child abuse, or homicide, either as offensive wounds (caused by the perpetrator) or defensive marks (inflicted during struggle) (53). The goal of bite mark analysis is to determine whether a specific individual could have caused the observed injury and to assess the evidentiary value of the mark in the context of the investigation (53).

The process typically begins with the documentation of the bite mark on the victim's skin or other surfaces using photography (with scale), infrared imaging, or 3D scanning (54). A forensic odontologist then compares the pattern, size, and alignment of the mark to the suspect's dentition using dental casts, overlays, and digital superimposition techniques (54). Analytical features such as tooth spacing, rotations, arch form, missing teeth, and incisal edge morphology are evaluated (55). However, bite marks on skin are highly variable, as skin is a flexible, elastic medium that changes over time due to swelling, healing, or decomposition. These inherent biological and temporal changes can distort the original pattern, introducing a high degree of subjectivity into interpretation and limiting reproducibility across examiners (56).

Indeed, in recent years, the scientific credibility of bite mark analysis has come under significant scrutiny. The

2009 report of the National Academy of Sciences (NAS) concluded that there was insufficient scientific foundation to support the reliability of bite mark identification, highlighting the absence of standardized protocols, the lack of reproducibility in repeated analyses, and significant inter-examiner variability (57). Similarly, the 2016 report of the President's Council of Advisors on Science and Technology (PCAST) found that bite mark analysis had not been scientifically validated through rigorous empirical testing, and that population-based error rates remained unknown (57). Both reports emphasized that elastic properties of human skin, post-injury tissue changes, examiner bias, and the absence of large-scale, blinded validation studies further undermine its accuracy (57). Several wrongful convictions in high-profile cases, later overturned by DNA evidence, have highlighted the potential dangers of overreliance on this method (58). As a result of these methodological weaknesses, some courts have restricted or excluded bite mark evidence entirely, applying stricter admissibility standards such as the Daubert or Frye criteria (59).

Many experts now advocate for a more cautious and limited use of bite mark analysis—as a tool for excluding suspects or indicating a potential bite injury, rather than as definitive identification evidence (58). While emerging technologies such as digital imaging, 3D modeling, and machine learning offer promise for improving standardization and accuracy, their forensic admissibility will ultimately depend on robust validation and clearly defined error rates (60,61). Until then, bite mark evidence should be carefully weighed within a broader forensic framework, emphasizing corroborative findings rather than isolated conclusions.

DENTAL EVIDENCE IN ABUSE AND NEGLECT CASES

Beyond pattern injuries such as bite marks, dental evidence also plays a vital role in the recognition and documentation of abuse, particularly in vulnerable populations such as children, elderly individuals, and persons with disabilities. Because the oral and maxillofacial regions are frequently targeted in physical assaults, dental professionals are in a unique position to detect injuries that might otherwise go unnoticed (62,63). Common indicators include lacerations, contusions, burns, avulsed or fractured teeth, frenulum tears, and unexplained facial swelling, especially when the clinical findings are inconsistent with the provided history (62,63).

In Türkiye, the establishment of multidisciplinary protection centres in university hospitals and the creation of advocacy centres have enhanced coordinated responses to abuse (64,65). Non-governmental organizations have further contributed through professional and public education (64,65). According to national reporting data, physical and sexual abuse remain the most frequently documented forms of maltreatment, and in a considerable proportion of cases, the perpetrator is an acquaintance outside the immediate family (64,65). However, variations in inter-institutional coordination, limitations in professional training, and inconsistencies in reporting processes continue to affect the timely identification and effective management of abuse cases in clinical practice.

Physical abuse often presents with distinct intraoral and perioral signs. Bilateral injuries, bruises in protected areas (such as the soft palate or inner lips), and patterned lesions consistent with implements (e.g., cords, belts, or fingers) may indicate inflicted trauma. Torn labial or lingual frenula in non-ambulatory infants have been linked to forced feeding or blunt trauma. Chronic neglect may manifest as rampant caries, untreated infections, or severe malnutrition, signalling a failure to provide adequate care (66,67). For example, a case report describes a 9-year-old victim identified during dental treatment, where a hematoma in the left orbit and burns on the left hand and lips prompted notification of the authorities (68).

Sexual abuse can also present with specific oral findings, such as petechiae on the palate, sexually transmitted infections in the oral cavity, or bite marks in the perioral region (67,69). Globally, the prevalence of childhood sexual abuse (CSA) has been estimated at 12.7% in self-report studies and 0.4% in informant studies, with notable regional and gender variations. Self-reported CSA rates are higher among females (18.0%) compared with males (7.6%). The lowest rates for both girls (11.3%) and boys (4.1%) are reported in Asia, whereas the highest rates are observed for girls in Australia (21.5%) and for boys in Africa (19.3%). These findings underscore CSA as a significant global concern, while also highlighting the influence of methodological differences on reported prevalence rates (70).

Dental professionals are often among the first mandated reporters, and forensic odontologists may be called upon to provide expert testimony or consult in multidisciplinary protection teams. When abuse is suspected, detailed documentation using photographs (with consent), written records, and timely reporting are essential. The forensic odontologist must approach these cases with sensitivity, clinical objectivity, and strict adherence to ethical and legal standards. Collaboration with pediatricians, forensic nurses, psychologists, and social workers is crucial to ensure a comprehensive and victim-centred response. Through early recognition and proper documentation, dental professionals can play a transformative role in protecting vulnerable individuals and supporting justice (67,69).

LEGAL AND ETHICAL CONSIDERATIONS IN FORENSIC ODONTOLOGY

The integration of dental evidence into legal proceedings requires not only scientific accuracy but also strict adherence to a unified framework of legal and ethical standards. In many jurisdictions, findings presented by forensic odontologists may be used to establish identity, corroborate or refute allegations of abuse, or support criminal charges. Therefore, forensic dental opinions must meet the criteria of admissibility in court, including scientific validity, reliability, and relevance (71,72). International guidelines such as ISO 21043 and the European Network of Forensic Science Institutes (ENFSI) best-practice documents provide standardised protocols for evidence collection, preservation, and reporting, ensuring consistency and credibility in legal contexts (73). The expert's report must clearly outline the methods used, the basis for conclusions, and any limitations of the analysis to ensure transparency and accountability (74).

One of the core legal responsibilities of a forensic odontologist is to act as an expert witness (75). This role requires not only technical expertise but also the ability to communicate findings clearly and objectively to a legal audience, including judges, attorneys, and juries who may have no scientific background (75,76). The odontologist must remain impartial, avoiding advocacy for either party, and instead present a scientifically grounded opinion. To support the chain of custody, all evidence—such as dental casts, radiographs, or photographs—must be properly labeled, preserved, and documented to prevent tampering, loss, or misinterpretation (75,76).

Ethical considerations are inherently linked to legal responsibilities and must be addressed within the same framework. Particular caution is required in areas where scientific consensus is lacking, such as bite mark analysis. Overstatement of findings or failure to acknowledge uncertainty may lead to miscarriages of justice, including wrongful convictions (57,58). Forensic odontologists must also balance confidentiality with mandatory reporting obligations, particularly in cases involving suspected abuse or human rights violations, ensuring that both professional ethics and legal duties are fulfilled. Additionally, the examination of living individuals—such as age estimation in migrants or bite mark documentation in abuse cases—

raises important questions about informed consent, privacy, and human dignity. As the field continues to advance, ethical frameworks must evolve alongside scientific techniques to uphold both professional integrity and human rights.

LEGAL OBLIGATIONS AND MANDATORY REPORTING

In addition to their scientific and ethical responsibilities, forensic odontologists—and, more broadly, dental professionals—are bound by specific legal obligations, especially when encountering signs of abuse, neglect, or other criminal activity (77). In many jurisdictions, healthcare providers, including dentists, are classified as mandatory reporters. This means they are legally required to report suspected cases of child abuse, domestic violence, elder neglect, or other forms of mistreatment to relevant authorities, even if the victim does not disclose abuse directly (77). Failure to do so may result in legal consequences, including professional disciplinary action or criminal liability (77).

In Türkiye, this obligation is explicitly stated in the Turkish Penal Code, Article 279 (Failure of a Public Official to Report a Crime) and Article 280 (Failure of a Healthcare Professional to Report a Crime). Article 279 mandates that public officials who become aware of a crime that requires investigation or prosecution and fail to inform the competent authorities without delay may face imprisonment from six months to two years, with increased penalties if the offense involves vulnerable groups. Article 280 similarly requires healthcare professionals to report suspected crimes encountered in the course of their duties, with penalties of up to one year of imprisonment for noncompliance. These provisions are intended to ensure timely intervention and protection of victims, particularly children and individuals unable to defend themselves.

Despite the clear legal framework, studies have documented implementation gaps, such as insufficient training in recognizing forensic indicators of abuse and low compliance rates with mandatory reporting obligations among healthcare professionals. Common barriers include uncertainty about diagnostic thresholds, lack of familiarity with reporting procedures, fear of legal repercussions if suspicions are unfounded, and perceived threats to patient–provider trust (78). Addressing these gaps requires structured training, interprofessional communication protocols, and institutional support to protect both patients and reporting clinicians.

The oral cavity is often one of the first anatomical regions to manifest signs of physical abuse. Dentists may observe patterned bruises, torn frenula, unexplained dental trauma, or signs of malnutrition. When such findings are inconsistent with the reported history or clinical expectations, they must raise a red flag (79,80). In such situations, the dentist's duty extends beyond documentation—it includes prompt notification of social services, law enforcement, or child protection agencies, depending on national legislation.

A concise workflow outlining who should report, when the obligation is triggered, and how the report should be submitted is presented in Figure 1. This step-by-step framework aims to assist clinicians in navigating the decision-making process while ensuring compliance with legal requirements and minimizing reporting delays.

Apart from abuse-related cases, forensic odontologists may be involved in age estimation of undocumented individuals, including migrants and asylum seekers (81). In such contexts, legal systems often request dental assessments to determine whether a person is under or over the age of 18, which can affect access to housing, legal representation, and protection. In these cases, the

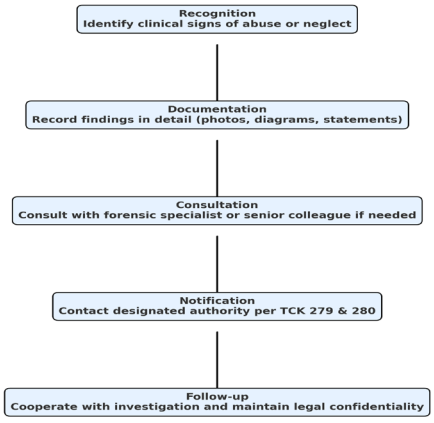


Figure 1. Workflow for mandatory reporting of suspected abuse in forensic odontology, illustrating the decision-making process for clinicians regarding who should report, when to initiate reporting, and the appropriate reporting channels in compliance with Articles 279 and 280 of the Turkish Penal Code.

odontologist must ensure that findings are communicated in a clear, objective, and non-biased manner, emphasizing the range of uncertainty inherent in age estimation techniques (81).

In summary, the practice of forensic odontology is not limited to technical analysis or courtroom testimony—it also includes direct legal responsibilities that must be fulfilled ethically and consistently. Adherence to mandatory reporting laws and understanding the medico-legal framework in one's country are essential for ensuring both justice and professional accountability.

CHALLENGES AND FUTURE DIRECTIONS

Despite its critical role in forensic science, forensic odontology continues to face substantial scientific, institutional, and systemic challenges worldwide. One of the most persistent issues is the lack of standardization and global consensus regarding many of its core methods (82). Techniques such as bite mark analysis and dental age estimation vary in their application, interpretation, and legal acceptance from one jurisdiction to another (83). This lack of methodological harmonization undermines the reliability and credibility of forensic dental evidence in legal proceedings and limits international collaboration.

A particularly pressing concern is that in many countries, including Türkiye, forensic odontology is not formally recognized as a distinct scientific discipline or specialty within dentistry (84). It is often practiced by general dentists with limited or no formal training in forensic protocols. This results in inconsistent quality, insufficient academic development, and weak integration into the broader forensic system. In contrast, countries such as the United Kingdom, Australia, and the United States have institutionalized forensic odontology through dedicated postgraduate programs, national guidelines, and official accreditation pathways (71). In Türkiye, the absence of such formal recognition stems from both legal and institutional barriers. For instance, the Turkish Ministry of Health's specialty list for dentistry does not include forensic odontology, preventing the establishment of accredited residency or postgraduate programs. Consequently, dentists involved in forensic cases—often appointed by prosecutors or courts—receive no standardized training or certification in evidence collection, dental record comparison, or age estimation. An archival review conducted at Istanbul University Faculty of Dentistry's forensic case records revealed notable inconsistencies in case documentation, the scope of recorded dental findings, and the integration of radiographic evidence, further illustrating the fragmented nature of practice in the absence of formal guidelines (85).

The practical consequences of this regulatory vacuum are evident in case management. Without a structured forensic odontology network, identification processes in mass disasters or complex criminal cases can be delayed, as dental evidence may not be collected or analyzed promptly. In some instances, general dentists are called upon to provide expert opinions without access to the ante-

mortem records or imaging tools necessary for high-quality comparisons. Moreover, the lack of formally recognized experts has occasionally resulted in forensic dental reports being challenged in court, with judges questioning their admissibility due to the absence of an official specialty title. These challenges ultimately reduce the potential contribution of dental evidence to the justice system.

Recent advances in AI and machine learning have demonstrated substantial potential in enhancing forensic odontology. Studies using convolutional neural networks (CNNs) and other deep-learning architectures have reported accuracy rates exceeding 90% in tasks such as dental age estimation, bite mark classification, and postmortem dental matching. These performance levels often match or surpass those of experienced human examiners, highlighting AI's ability to increase objectivity and reproducibility. However, most available studies are based on limited, homogeneous datasets, which restricts generalizability across different populations. This underlines the need for the development of large, diverse, and globally representative dental image databases to ensure model validity. To maximize the benefits of these technologies, there is an urgent need for internationally accepted protocols that define standardized methods for data collection, annotation, model training, and validation (86,87).

The path forward for forensic odontology will require more than just scientific innovation—it demands structural reform, international cooperation, and integration into national forensic strategies. For Türkiye, concrete steps could include establishing accredited postgraduate programs, embedding forensic odontology modules into undergraduate curricula, and creating national guidelines in collaboration with the Ministry of Justice and the Council of Forensic Medicine. On a global scale, building cross-border networks for data sharing, developing population-specific age estimation models, and expanding AI-driven dental identification systems will be essential. By combining technological progress with regulatory recognition and professional training, forensic odontology can evolve from a fragmented field into a robust, reliable, and internationally respected discipline—capable of contributing decisively to both justice and disaster victim identification efforts.

CONCLUSIONS

Forensic odontology plays a critical role in human identification, age estimation, trauma evaluation, and the assessment of dental evidence in abuse or neglect cases. As highlighted in this review, persistent gaps in standardization, training, and institutional recognition must be addressed to strengthen the scientific and legal credibility of the field. Priority should be given to the development of standardized global protocols, expansion of structured training programs, and implementation of population-specific research. Emerging technologies such as AI-based age estimation and advanced imaging should be integrated with rigorous validation to ensure reliability across diverse settings. In low-resource environments, cost-effective tools and accessible training modules are crucial to support equitable application. Upholding strict ethical standards, including mandatory reporting and impartial expert testimony, remains fundamental to maintaining public trust. By addressing these priorities, forensic odontology can advance toward becoming a more standardized, respected, and globally integrated discipline.

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