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REVIEW ARTICLE

Artificial Intelligence in Forensic Dentistry: Evidence-Based Insights

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Abstract

Background: Artificial intelligence (AI) is increasingly being investigated as a decision-support technology in forensic dentistry (forensic odontology). Potential applications include antemortem-postmortem dental comparison, candidate retrieval from large radiographic databases, dental age estimation, biological-sex estimation, and structured documentation in disaster victim identification (DVI).

Methods: This narrative, evidence-informed review prioritized peer-reviewed systematic and scoping reviews, representative validation studies, the 2023 National Institute of Standards and Technology (NIST) scientific-foundation review of bite-mark analysis, the 2023 INTERPOL DVI Guide, and applicable Indian legal and data-protection sources available through July 2026.

Results: Machine-learning and deep-learning models can detect complex image patterns and may improve speed and consistency in defined tasks. However, high performance reported in retrospective research datasets should not be equated with proven casework reliability: much of the literature remains limited by small or single-population datasets, heterogeneous methods, limited external validation, incomplete reporting of uncertainty, and the risk of spectrum or selection bias. Bite-mark comparison requires particular caution, because contemporary scientific-foundation reviews have found insufficient support for its core premises, and AI cannot correct limitations arising from biological distortion, unreliable ground truth, or an unvalidated forensic method. In India, implementation additionally requires attention to data protection, cybersecurity, chain of custody, electronic-record requirements, expert interpretation, and the preservation of human oversight.

Conclusions: The present evidence supports AI as an assistive and triage tool in forensic odontology, not as an autonomous source of identification or a substitute for a qualified forensic odontologist. Responsible adoption depends on representative data, external validation, transparent reporting, and enforceable governance safeguards.

Keywords: Artificial intelligence; dental identification; forensic odontology; machine learning; disaster victim identification; age estimation

Introduction

Forensic dentistry contributes to human identification and other medico-legal investigations through the examination and comparison of dental and oral evidence. Teeth, restorations, prostheses, implants, and supporting structures may survive decomposition, trauma, and heat better than many soft tissues. Consequently, dental comparison can be particularly valuable when visual recognition is impossible and reliable antemortem records are available.[1,2]

Conventional dental identification compares antemortem (AM) information with postmortem (PM) findings, including dental charts, radiographs, restorations, missing teeth, root morphology, pathological changes, prostheses, and implant characteristics. The probative strength arises from the overall pattern of concordant features and the absence of unexplained discrepancies; it should not be expressed as an unsupported assumption that every dentition is universally unique.

AI refers broadly to computational methods designed to perform tasks such as classification, pattern recognition, prediction, and decision support. Machine learning (ML) learns statistical relationships from structured data, whereas deep learning (DL), including convolutional neural networks

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(CNNs), is frequently used for image analysis. Reviews of AI in forensic odontology describe four recurring domains: dental comparison, age estimation, biological-sex estimation, and bite-mark research.[3-5]

The principal promise of AI is not autonomous identification but efficient analysis of large datasets, reproducible measurement, and prioritization of possible matches for expert review. Any reported performance must be interpreted in relation to the study population, reference standard, image quality, training-test separation, external validation, and the consequences of false-positive and false-negative results.

Scope and Approach

This article is a narrative, evidence-informed review. Priority was given to peer-reviewed systematic or scoping reviews, representative validation studies, the 2023 National Institute of Standards and Technology (NIST) scientific-foundation review of bite-mark analysis, the 2023 INTERPOL DVI Guide, and applicable Indian legal and data-protection sources available through July 2026. It is not a systematic review or meta-analysis and does not provide a pooled estimate of diagnostic or identification performance. Table 1 provides a consolidated summary of the major applications, available evidence, limitations, ethical and legal concerns, and recommended safeguards.

Applications of Artificial Intelligence in Forensic Odontology

Dental Identification and Database Matching

Automated dental comparison is one of the most defensible potential uses of AI in forensic odontology because it builds on the established AM-PM comparison workflow. Algorithms may segment teeth, identify restorations and missing teeth, encode anatomical features, and rank candidate matches from panoramic radiographs or other dental images. CNN-based systems have shown promising performance in research settings, including automatic identification from panoramic radiographs.[4,6]

In DVI operations, the operational value lies in triage. A computer system can rapidly shortlist records that appear similar, but a qualified forensic odontologist must review the original AM and PM material, assess image quality and discrepancies, and document the basis of the opinion. INTERPOL guidance assigns forensic odontologists to individual dental comparisons and places final identification decisions with the multidisciplinary Identification Board.[2] An AI-generated similarity score is therefore a lead for expert reconciliation, not a self-sufficient declaration of identity.

Dental Age Estimation

Dental age estimation may be required when chronological age is unknown or disputed, including unidentified remains and certain civil, immigration, or criminal-law contexts. Traditional methods evaluate tooth development, eruption, third-molar maturation, pulp-to-tooth ratios, secondary dentin deposition, and other age-related changes. AI can automate segmentation, staging, or regression from panoramic and other maxillofacial radiographs.[7-9]

Reported accuracy is often encouraging, but age estimates remain population- and method-dependent. A mean absolute error or classification accuracy from a development dataset does not demonstrate equivalent performance in a new population. Models intended for legal thresholds require external validation near the relevant cut-off, calibrated uncertainty, documented image-acquisition conditions, and analysis of subgroup performance. The final report should present an estimated range and limitations; it should not imply that AI can determine an exact chronological or legal age.

Biological-Sex Estimation

AI models have been trained to estimate biological sex from tooth dimensions, mandibular and craniofacial morphology, and panoramic radiographs. Large retrospective datasets have demonstrated that CNNs can learn sex-associated imaging patterns.[8,10] Nevertheless, performance is influenced by age distribution, ancestry, dental status, treatment history, image equipment, and local population characteristics.

The preferred forensic expression is biological-sex estimation rather than absolute sex determination. Dental or mandibular models should be treated as supportive evidence, especially when more informative skeletal or genetic evidence is available. Reports should state the reference population, model version, probability or confidence measure, and known limitations, and should avoid conflating biological sex with gender identity.

Bite-Mark Evidence

Bite-mark comparison on human skin is scientifically distinct from AM-PM dental identification and should not inherit the latter's evidentiary reputation. The 2023 NIST review concluded that the principal premises of bite-mark analysis were not supported by sufficient data: individual-level uniqueness of anterior dental patterns had not been established, those patterns are not consistently transferred to skin, and defining characteristics have not been shown to be accurately interpreted for source exclusion or non-exclusion.[11]

AI may assist research tasks such as image enhancement, segmentation, geometric measurement, or assessment of image quality. It cannot, however, validate an unreliable reference label, reverse unpredictable skin distortion, or establish source attribution where the underlying forensic method lacks an adequate scientific foundation. Accordingly, claims that AI makes bite-mark identification objective or definitive should be avoided. Any use must be narrowly

framed, transparently validated, and subject to strict legal scrutiny.

DVI Documentation and Workflow Support

AI may also support non-identification tasks: transcription of dental findings, consistency checks in odontograms, image-quality alerts, duplicate-record detection, multilingual data extraction, and prioritization of incomplete files. These uses may reduce administrative burden without transferring the final opinion to an algorithm. Human verification remains essential because an automatically propagated charting error can contaminate multiple stages of reconciliation.

Future Potential

Future systems may integrate dental radiographs, three-dimensional scans, clinical photographs, implant data, facial or craniofacial information, fingerprints, and DNA results. Multimodal systems could improve candidate retrieval, especially when one source is incomplete. AI-assisted three-dimensional reconstruction, automated quality control, and portable field imaging may also strengthen DVI capacity, provided acquisition standards and chain-of-custody controls are maintained.[2,12]

Federated learning and privacy-preserving analytics may allow institutions to develop broader models without routinely pooling identifiable dental records in one location. Synthetic data may supplement training, but it cannot replace representative real-world validation. Future research should emphasize prospective and multicentre evaluation, prespecified outcomes, transparent reporting, open error analysis, calibration, clinically relevant comparators, and external validation across populations and imaging devices.

Limitations, Ethical Issues, and Legal Considerations

Validity, Bias, and Generalizability

AI performance depends on the data, labels, and study design used to develop it. Biased or unrepresentative datasets can produce systematically different error rates across age groups, populations, socioeconomic settings, dental conditions, or imaging devices. Small datasets and leakage between training and test sets can create deceptively high accuracy. Independent external validation is therefore more important than a single headline metric.[3-5,13]

Explainability, Accountability, and Human Oversight

Forensic opinions must be capable of being explained and challenged. A black-box score without a documented model version, input provenance, validation history, threshold, and known error characteristics is difficult to evaluate in court. The forensic odontologist should retain responsibility for examining the source material, interpreting the output in context, documenting disagreement with the model, and communicating uncertainty. Automation bias is a particular risk: an early algorithmic suggestion may influence later human interpretation even when the suggestion is wrong.[5,13]

Privacy, Security, and Data Governance

Dental images and records can be identifiable personal data. In India, collection, digitization, model development, cross-institutional sharing, retention, and cloud processing must be assessed under the Digital Personal Data Protection Act, 2023 and the Digital Personal Data Protection Rules, 2025, together with other applicable legal duties and statutory exemptions.[14,15] Responsible governance should include purpose limitation, data minimization, role-based access, encryption, audit logs, retention schedules, de-identification where appropriate, contractual controls for processors, and a documented response plan for data breaches.

Chain of Custody and Admissibility

An AI output does not authenticate itself. For casework, the record should preserve the original image, acquisition metadata, hash or other integrity controls where used, every material transformation, operator identity, software and model version, settings, timestamps, and the final expert interpretation. In India, the Bharatiya Sakshya Adhiniyam, 2023 governs expert opinion and electronic or digital records; applicable certification and foundational requirements must be addressed when electronic material is tendered in evidence.[16] The expert should be able to explain what the system did, what it did not do, its validated error characteristics, and why the conclusion remains scientifically justified.

Global and Indian Perspectives

Global Perspective

International research has expanded rapidly, particularly in radiographic identification and age or biological-sex estimation. Nevertheless, publication of high-performing models has outpaced independent casework validation and standardized deployment. The most mature near-term use is likely to be controlled decision support within established workflows, with expert review and quality assurance, rather than autonomous forensic conclusions.[3-5,12]

Indian Scenario

India has a large and diverse population, variable record quality, and multiple imaging platforms. These factors create both a strong need and a significant validation challenge. Models trained predominantly on foreign or narrowly selected populations should not be presumed transportable to Indian casework. Indian literature has historically reported uneven maintenance of dental records, limited specialist capacity, and the absence of organized dental DVI arrangements, all of which constrain implementation.[17]

Table 1: Artificial intelligence in forensic dentistry: applications, evidence, limitations, ethical and legal concerns, and safeguards for responsible adoption

Aspect	*Key points*
Current applications of AI in forensic dentistry	Antemortem-postmortem dental identification and candidate retrieval from radiographic databases; dental age estimation; biological-sex estimation; bite-mark research (research context only); DVI documentation and workflow support, including charting consistency checks, image-quality alerts, and duplicate-record detection.
Available evidence and level/quality of evidence	Predominantly retrospective, single-centre development studies summarized in systematic and scoping reviews; convolutional neural networks show promising accuracy for identification, age, and sex estimation in research datasets; prospective, multicentre casework validation is lacking; overall certainty of evidence is low to moderate and task-dependent.
Evidentiary limitations and sources of uncertainty	Small or unrepresentative datasets; heterogeneous methods and reference standards; risk of training-test leakage and spectrum or selection bias; incomplete reporting of uncertainty; population, method, and device dependence of age and sex estimates; bite-mark analysis lacks an adequate scientific foundation [11], which AI cannot remedy.
Ethical and legal concerns	Privacy and governance of identifiable dental data under the Digital Personal Data Protection Act, 2023 and Rules, 2025 [14,15]; chain of custody and admissibility of electronic records under the Bharatiya Sakshya Adhiniyam, 2023 [16]; accountability and explainability of expert opinion; automation bias; risk of overstating scientific certainty in court.
Validation, bias, explainability, and generalisability	External validation across institutions, populations, and imaging devices; subgroup error rates and calibrated uncertainty; locked and documented software and model versions; transparent, challengeable outputs rather than black-box scores; models trained on foreign or narrowly selected populations should not be presumed transportable to Indian casework.
Practical safeguards and recommendations for responsible adoption	Predefined intended use, operators, and prohibited uses; representative data with independently verified reference standards; mandatory review by a qualified forensic odontologist; prohibition of autonomous identification and legal-age conclusions; audit trails, version locking, and post-deployment monitoring with suspension when performance drifts outside validated limits.

A realistic Indian roadmap would begin with multicentre, population-relevant datasets; standardized dental charting and imaging; clear institutional governance; prospective validation; and collaboration among forensic odontologists, oral radiologists, computer scientists, forensic laboratories, law-enforcement agencies, and legal experts. Pilot deployment should be restricted to predefined tasks and audited before expansion.

Minimum Safeguards Before Casework Deployment

- Define the intended use, target population, operator, and prohibited uses before validation.
- Use representative data and an appropriate, independently verified reference standard.
- Perform external validation across institutions, populations, and imaging devices; report uncertainty and subgroup error rates.
- Lock and document the software and model version used in each case; preserve original evidence and an auditable processing history.
- Require qualified human review and prohibit autonomous identification or legal-age conclusions.
- Establish privacy, cybersecurity, access-control, retention, incident-response, and vendor-governance procedures.
- Monitor post-deployment performance, document overrides and failures, and suspend use when performance drifts outside validated limits.

Conclusion

The main conclusions and take-home messages of this review are as follow:

- AI can improve the speed, consistency, and organization of selected forensic-dental tasks, particularly candidate retrieval from dental databases, radiographic analysis, age estimation, biological-sex estimation, and DVI documentation.
- Its value is greatest when the intended task is narrow, the data are representative, performance is externally validated, and the output is interpreted by a qualified forensic odontologist.
- High performance in retrospective research datasets does not establish casework reliability; independent, population-relevant external validation should precede any forensic deployment.
- The technology must not be allowed to overstate the underlying science, particularly for bite-mark comparison on skin, where foundational validity problems cannot be remedied by computational methods.
- Transparent methods, uncertainty reporting, data governance, chain of custody, legal compliance, and human accountability are essential in every application.
- For practice, AI outputs should be treated as investigative leads for expert reconciliation, with final responsibility retained by the forensic odontologist and, in DVI, the multidisciplinary Identification Board.

- For research, priorities include multicentre and population-relevant datasets, prospective evaluation, standardized and transparent reporting, calibration, and open error analysis.
- The current evidence supports carefully governed AI-assisted forensic odontology, not autonomous forensic decision-making.

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