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Role of Artificial Intelligence in Forensic Odontology: A Narrative Review

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ABSTRACT

Abstract

Artificial Intelligence (AI) has emerged as a transformative tool in forensic odontology, enhancing the accuracy and efficiency of human identification processes. This systematic review examines the applications of AI in forensic odontology, focusing on its role in dental age estimation, sex determination, bite mark analysis, and human identification through dental records. A comprehensive literature search was conducted across PubMed and Scopus databases, covering studies published from January 2010 to February 2025. A total of 18 relevant articles were included in this review. The findings indicate that AI, particularly through machine learning (ML) and deep learning (DL) algorithms, significantly improves the precision and objectivity of forensic dental analyses. Despite these advancements, challenges such as data privacy, ethical considerations, and the need for large, diverse datasets persist. Future research should address these issues to fully integrate AI into routine forensic odontology practice.

KEYWORDS

• Artificial intelligence • Lip print • Palatal rugae • Radiograph • Neural network

INTRODUCTION

Artificial Intelligence (AI) has emerged as a transformative tool in various scientific disciplines, including forensic odontology, which applies dental science to legal investigations for human identification, age estimation, bite mark analysis, and mass disaster victim recognition.[1] Traditional forensic odontology techniques, although widely used, face significant challenges such as inter-examiner variability, subjective interpretation, and limitations in analyzing complex dental evidence.[2] AI, with its advanced computational capabilities, machine

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learning algorithms, and pattern recognition techniques, offers a promising avenue to enhance the accuracy, efficiency, and reliability of forensic odontological assessments.[3] The origins of AI can be traced back to the mid-20th century, with early developments in machine learning, expert systems, and neural networks laying the foundation for modern AI applications.[4] In recent decades, advances in deep learning, computer vision, and big data analytics have facilitated AI integration into various fields, including healthcare, forensic sciences, and biometrics.[2] Despite its potential, forensic odontology presents several methodological challenges. Gender identification based on dental morphology is often hindered by overlapping characteristics between sexes, requiring more robust and objective analytical tools.[5] Bite mark analysis remains one of the most contentious areas in forensic science due to issues such as skin distortion, low inter-examiner agreement, and lack of standardized methodologies.[6] Age estimation, another critical aspect of forensic odontology, is affected by individual variations in dental development influenced by genetic and environmental factors, reducing the accuracy of conventional assessment methods.[7] Moreover, in mass disaster scenarios, forensic experts must process large volumes of dental records rapidly, a task that is often time-consuming and prone to human error.[8] AI-driven approaches, including automated image processing, deep learning-based classification, and predictive modeling, offer significant improvements in these areas by enabling objective, data-driven decision-making.[5] AI algorithms can refine gender classification based on dental features, reduce subjectivity in bite mark comparisons, and enhance the precision of age estimation through radiographic and morphological analysis.[9] Additionally, AI-powered forensic databases and matching algorithms can facilitate the rapid and accurate identification of disaster victims, significantly improving forensic response efficiency.[10] Despite these advancements, AI in forensic odontology is not without limitations. The reliability of AI models is contingent upon high-quality; diverse training datasets and ethical concerns regarding bias, transparency, and legal admissibility must be addressed. The integration of AI also necessitates forensic experts' validation to ensure its accuracy and credibility in legal contexts. This review aims to critically analyze AI's role in forensic odontology, assessing its applications, advantages, and limitations while highlighting its potential to revolutionize forensic investigations and improve the objectivity and reliability of forensic dental analyses.

METHODOLOGY

Study Design

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure a transparent, comprehensive, and reproducible methodology. The primary objective of this review was to evaluate and synthesize existing literature on the application of Artificial Intelligence (AI) in forensic odontology, specifically in the domains of gender identification, bite mark analysis, age estimation, and mass disaster victim identification.

Search Strategy

A comprehensive and structured literature search was conducted across multiple electronic databases, including **PubMed, Scopus, Web of Science and Google Scholar.** The search was performed using a combination of Medical Subject Headings (MeSH) terms and relevant keywords, ensuring the inclusion of all relevant studies. The following search terms were used:

- "Artificial Intelligence" OR "Machine Learning" OR "Deep Learning" OR "Neural Networks"
- "Forensic Odontology" OR "Forensic Dentistry"
- "Gender Identification" OR "Sex Determination"
- "Bite Mark Analysis" OR "Pattern Recognition"
- "Age Estimation" OR "Dental Age Assessment"
- "Mass Disaster Victim Identification" OR "Dental Biometrics"

Boolean operators (AND/OR) were applied to refine the search and retrieve relevant articles. Additionally, a manual search was performed by screening the reference lists of included studies to identify any additional relevant

publications.

Eligibility Criteria

Inclusion Criteria

Studies were included in the review if they met the following criteria:

1. **Study Type:** Original research articles, systematic reviews, meta-analyses, and conference papers focused on AI applications in forensic odontology.
2. **Publication period:** Studies published between 2010 and 2025 to ensure the inclusion of recent advancements in AI technology.
3. **Language:** Articles published in English.
4. **AI Application:** Studies employing AI-based techniques such as machine learning, deep learning, neural networks, computer vision, or automated image analysis in forensic odontology.
5. **Forensic Application:** Studies addressing AI applications in gender identification, bite mark analysis, age estimation, or mass disaster victim identification using dental records.

Exclusion Criteria

Studies were excluded based on the following criteria:

1. **Non-AI studies:** Articles focusing solely on traditional forensic odontological methods without AI involvement.
2. **Non-forensic studies:** Research on AI applications in general dentistry or medical imaging without relevance to forensic investigations.
3. **Case reports and opinions:** Editorials, expert opinions, and case reports that lacked original AI-based data analysis.
4. **Unpublished or non-peer-reviewed sources:** Preprints, dissertations, or non-peer-reviewed conference abstracts.

Ethical Considerations

Since this study is a systematic review, no direct human or animal subjects were involved. Ethical approval was not required. However, all reviewed studies were peer-reviewed and published in recognized journals, ensuring adherence to ethical research practices.

DISCUSSION

Bite mark analysis

Artificial Intelligence (AI) has shown significant potential in improving bite mark analysis, a historically controversial aspect of forensic odontology. Traditional bite mark analysis has been criticized due to inconsistencies in human interpretation, skin distortion, and the lack of standardized methodologies. AI-driven image processing and deep learning algorithms provide an objective, data-driven approach to identifying and comparing bite marks with enhanced accuracy. A recent systematic review by Khan *et al.* comprehensively evaluated AI applications in forensic odontology and emphasized the role of deep learning in bite mark analysis. The study found that convolutional neural networks (CNNs) significantly improved bite mark identification accuracy, reducing human bias in forensic interpretations.[11] Another study by Mahasantipiya *et al*. used a deep learning-based hybrid AI model combining CNNs and Support Vector Machines (SVMs) to classify bite marks with an accuracy of 91.2%. This study highlighted that AI-based classification could differentiate between human and non-human bite marks more effectively than traditional methods.[6]

Similarly, Chandramouleeswaran utilized a machine learning model trained on augmented forensic databases containing various bite mark impressions and achieved a substantial increase in matching precision. Their research validated the use of AI to reduce variability and increase the reproducibility of bite mark analysis.[12] Additionally, a study by Thurzo *et al.* explored AI-enhanced super-resolution techniques to reconstruct low-quality bite mark images, enabling forensic experts to extract meaningful data from degraded evidence.[13] This advancement is crucial in forensic investigations where bite mark clarity is often compromised due to environmental conditions.

While AI offers numerous advantages in bite mark analysis, certain challenges remain. One of the primary limitations is the dependence on high-quality training datasets; AI models require extensive, well-annotated forensic bite mark images to improve accuracy. A study by

Maji *et al*. found that AI's performance declined when trained on small or imbalanced datasets, leading to potential misclassifications.[14]

Additionally, the black-box nature of deep learning models presents issues regarding explainability and legal admissibility in court proceedings. Some forensic experts argue that AI's decision-making process must be interpretable to be considered reliable forensic evidence. Ethical concerns, such as the potential for AI bias due to non-representative datasets, also need to be addressed. Overall, while AI enhances bite mark analysis by improving accuracy, standardization, and reproducibility, its integration into forensic odontology requires rigorous validation, larger datasets, and legal considerations to ensure its forensic credibility.

Gender identification with AI

Artificial intelligence (AI) has significantly advanced forensic odontology, particularly in gender identification using dental structures. Traditional methods, such as morphometric analysis of dental features and radiographic measurements, often rely on subjective interpretation, whereas AI provides a more objective and efficient approach.

Recent studies have demonstrated the effectiveness of machine learning (ML) and deep learning (DL) models in automating and enhancing gender classification from dental records. Nafiyat *et al.* (2024) analyzed multiple machine learning methods, including Support Vector Machines (SVMs), Random Forest (RF), and Convolutional Neural Networks (CNNs), for gender identification using panoramic radiographs. Their study found that CNNs outperformed traditional classifiers, achieving an accuracy of 94.5%.[15]

Similarly, Setiawardani *et al*. (2025) utilized AI-based 3D skull reconstruction and deep learning models to classify gender from skull and dental features. Their results showed that AI-enhanced 3D image processing improved gender classification accuracy by 8-10% compared to manual assessments.[16] Systematic review by Dashti *et al.* assessed AI accuracy in gender determination using orthopantomograms (OPGs) and found that Deep Neural Networks (DNNs) achieved a 96% accuracy rate, surpassing conventional cephalometric and morphometric techniques.[17] Supriyadi *et al.* (2024) explored hybrid AI models combining SVM and CNN, applying them to forensic datasets with dental images. Their model exhibited a 92% classification accuracy, demonstrating AI's ability to handle complex variations in dental morphology.[18] Additionally, Şenol *et al.* (2024) used Artificial Neural Networks (ANNs) and machine learning algorithms to estimate gender from mandibular lingula morphology, achieving high accuracy rates and supporting AI's utility in forensic anthropology.[19]

AI-based forensic gender identification offers multiple advantages, including high accuracy, reproducibility, and the ability to process large datasets efficiently. AI models eliminate human bias and inter-examiner variability, leading to more objective results. Additionally, AI can analyze degraded or fragmented dental remains, aiding in mass disaster victim identification. However, methodological limitations persist. AI models require large, high-quality training datasets, and performance declines when trained on imbalanced or small datasets.

Moreover, AI's "black-box" nature raises concerns about explainability and legal admissibility in forensic investigations. Bias in AI training data, particularly if datasets lack diverse ethnic and population representations, could impact generalizability. While AI enhances gender identification in forensic odontology, further validation, standardized datasets, and interdisciplinary collaboration are necessary to ensure its forensic reliability.

Role of AI in age estimation

Artificial intelligence (AI) has significantly improved age estimation in forensic odontology, offering a more precise and automated approach than traditional methods. Conventional techniques, such as Demirjian's and Cameriere's methods, rely on radiographic analysis of dental development, but they often involve subjective interpretation and variability among forensic experts. AI, particularly machine learning (ML) and deep learning (DL) models, has enhanced the accuracy and consistency of age estimation by automating feature extraction and pattern recognition in dental radiographs.

A study by Boedi introduced a machine learning-assisted 5-part tooth segmentation method using cone-beam computed tomography (CBCT), improving the accuracy

of dental age estimation in adults.[20] Similarly, Faragalli *et al.* compared traditional linear regression models with AI-based techniques and found that deep neural networks (DNNs) significantly reduced estimation errors, making them more reliable for forensic investigations.[21]

Another study by Oliveira *et al.* applied machine learning algorithms to panoramic radiographs in a Brazilian population, demonstrating an accuracy of over 95% in age estimation using a hybrid convolutional neural network (CNN) and support vector machine (SVM) model.[22] Additionally, Ali M *et al*. explored an explainable AI (XAI) model for age and gender estimation, improving forensic interpretability and ensuring legal admissibility of AI-based decisions.[7]

A study by Patil *et al.* uses Artificial Neural Networks (ANN) for gender determination and compares results obtained with logistic regression and discriminant analysis using mandibular parameters as inputs. The discriminant analysis had an overall accuracy of 69.1%, logistic regression showed an accuracy of 69.9% and ANN exhibited a higher accuracy of 75%. The results revealed that ANN is a good gender prediction tool.[23]

AI offers numerous advantages, including higher accuracy, automation, and reproducibility, reducing the variability associated with human-based interpretations. AI models can analyze large datasets rapidly, making them particularly useful in forensic investigations involving mass disaster victim identification. Additionally, deep learning approaches can detect subtle changes in dental maturation, enabling precise age predictions.

However, methodological limitations persist. AI models require large, diverse, and well-annotated datasets for effective training; otherwise, they may produce biased results. Ethical and legal concerns arise regarding the black-box nature of deep learning algorithms, which makes it difficult to explain AI-generated predictions in a forensic or legal context. Moreover, inter-population variations in dental development may affect the generalizability of AI models, necessitating regional model adaptation.

Mass disaster and AI

Artificial intelligence (AI) has emerged as a vital tool in forensic odontology, particularly in mass disaster victim identification (DVI), where rapid and accurate processing of large datasets is crucial. Traditional forensic methods, including manual dental chart comparisons and radiographic analysis, can be time-consuming and prone to errors, especially in large-scale disasters such as earthquakes, tsunamis, and plane crashes.

AI, through machine learning (ML) and deep learning (DL) models, enhances speed, accuracy, and automation in dental-based victim identification. Mohammad *et al*. introduced an AI-powered Forensic Dental Estimation Lab (F-DentEst Lab), which utilizes automated dental age estimation and feature extraction algorithms to match victims' dental records efficiently.[24] Their study, conducted on a large Malaysian dataset, demonstrated a significant improvement in forensic dental matching accuracy, reducing manual workload for forensic odontologists.[24]

Similarly, Yusof *et al.* (2024) validated F-DentEst Lab for automated forensic dental age estimation, highlighting its potential in mass disasters where traditional methods struggle with large-scale processing. Their findings showed that AI-driven decision support systems significantly reduced human error, making forensic dental identification more reliable.[25] Another study by Singh *et al*. (2024) explored AI applications in age and sex determination using maxillofacial radiographs, crucial for mass disaster identification. Their systematic review demonstrated that convolutional neural networks (CNNs) and artificial neural networks (ANNs) significantly outperformed traditional forensic techniques, improving accuracy and efficiency in victim profiling.[26]

AI-based forensic techniques offer numerous advantages, particularly in speed, scalability, and accuracy. AI can rapidly analyze thousands of dental records, automating feature extraction, pattern recognition, and matching processes. It reduces human error and inter-examiner variability, leading to more consistent and reliable identifications. Additionally, AI can process degraded dental records, which are often the only available evidence in fire-related or water-related disasters.

The implementation of AI in orthodontics encounters multiple challenges, such as dataset limitations, ethical concerns, and legal considerations, which must be carefully

navigated for successful integration. AI models depend on extensive, high-quality datasets to facilitate accurate diagnosis and treatment planning; however, limited, biased, or unstandardized datasets can compromise predictive accuracy and diminish clinical reliability.[27] Moreover, integrating AI into existing clinical workflows demands regulatory approval and specialized professional training to ensure seamless application.[28] To overcome these obstacles, standardized data collection, robust validation protocols, and well-defined legal frameworks are essential to promote the safe and effective adoption of AI in orthodontics.

However, AI applications in forensic odontology face several challenges. AI models require large, diverse, and well-annotated datasets for training; otherwise, they risk bias and inaccurate predictions. Legal and ethical concerns arise regarding the admissibility of AI-generated identifications in court due to the black-box nature of deep learning algorithms, which may lack transparency in decision-making. Furthermore, AI systems must be continuously updated and validated across diverse populations, as dental patterns vary across ethnicities and age groups. Technical limitations, such as errors in AI-based image segmentation and feature misclassification, can also impact reliability.

CONCLUSION

AI-driven bite mark analysis, age estimation, gender identification in mass disaster or criminal investigations has demonstrated significant improvements in forensic odontology, particularly through deep learning and hybrid machine learning models. AI has significantly transformed victim identification by improving efficiency, accuracy, and automation in forensic odontology. However, further research is required to standardize AI applications, validate models across populations, and address ethical and legal concerns to ensure forensic credibility.

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