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RESEARCH ARTICLE

AMASSMENT OF ARTIFICAL INTELLIGENCE IN THE FIELD OF FORENSIC MEDICINE AND FORENSIC ODONTOLOGY – A SYSTEMATIC REVIEW

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Abstract: ***Background***: Forensic odontology, the study of dental evidence in criminal investigations and identification, has seen a surge in technological advancements, especially with artificial intelligence (AI). AI algorithms have shown potential in improving accuracy, speed, and reliability in identifying individuals from dental records. This systematic review aims to evaluate and synthesize recent developments in AI applications in forensic odontology, focusing on methodologies, accuracy, challenges, and potential areas for improvement.***Materials and Methods:*** A comprehensive literature search was conducted across major databases, including Elsevier,PubMed, Scopus, covering studies published from 2020 to 2024. Studies were selected based on inclusion criteria that required the use of AI in forensic odontology applications, including pattern recognition, dental record analysis, and identification processes. Data were extracted on AI methods used (e.g., machine learning, deep learning), performance metrics, datasets, and study limitations. The quality of studies was assessed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.***Results:*** The review identified 45 studies meeting the inclusion criteria. Among these, convolutional neural networks (CNNs) and other machine learning models demonstrated high accuracy in dental pattern recognition, with several studies reporting identification accuracy rates above 90%. Applications in bite mark analysis, dental age estimation, and post-mortem identification showed particularly promising results. However, variability in dataset quality, limited sample sizes, and challenges in standardizing AI models across different demographics were common issues. ***Discussion:*** The findings suggest that while AI holds great potential in forensic odontology, there are significant obstacles to widespread adoption. Variability in image quality and the need for large, diverse datasets to train robust models remain challenges. Additionally, ethical considerations, such as privacy concerns and potential biases in AI models, must be addressed to ensure accurate and equitable outcomes.***Conclusion:*** AI has the capacity to enhance forensic odontology by streamlining identification processes and improving accuracy. However, further research is needed to standardize methodologies, improve dataset diversity, and address ethical implications. Integrating AI-driven forensic odontology into legal frameworks will require collaboration between technologists, forensic experts, and policymakers to ensure reliability and trustworthiness in forensic investigations.

Keywords: Forensic odentology,machine learning,CNN, Artificial intelligence

INTRODUCTION

Forensic odontology plays a critical role in criminal investigations, disaster victim identification, and age estimation based on dental evidence. Traditional methods rely heavily on expert interpretation, which can be time-consuming and subject to human error. With the emergence of artificial intelligence (AI), particularly machine learning (ML) and deep learning (DL), there is a growing interest in automating and enhancing forensic odontology processes. AI has shown potential in analyzing complex dental patterns, detecting age-related changes, and identifying individuals based on unique dental characteristics, promising improvements in accuracy, speed, and reliability.

This systematic review examines recent literature from 2020 to 2024 on AI applications in forensic odontology. We aim to identify the AI techniques employed, evaluate the results achieved, discuss challenges, and outline future research directions for AI in this field.

1.1 Overview of AI in Forensic Odontology

Primary identifiers, such as fingerprinting, forensic odontology, and DNA profiling, are highly reliable for confirming identification. Forensic odontology, the simplest and quickest among these, involves identifying individuals by analyzing the unique structures of the oral cavity . This field is essential in medico-legal investigations, particularly in mass disasters, for identifying remains through dental records and human remains. It proves invaluable when bodies are severely damaged by events like tsunamis, earthquakes,

landslides, or bomb blasts, where traditional identification methods fail [1][2].

AI's introduction to forensic odontology aims to address issues in accuracy and efficiency. Machine learning models can classify dental records and detect patterns indicative of age or identity, while deep learning architectures, such as convolutional neural networks (CNNs), have been effective in image-based dental analysis. Notable applications include bite mark analysis, dental age estimation, and post-mortem identification. However, widespread implementation is hindered by factors such as limited datasets and concerns over model transparency and interpretability[3].

1.2 Key AI Techniques in Forensic Odontology

Machine Learning (ML): Machines can be trained to handle data more effectively through the application of machine learning (ML). Occasionally, we are unable to decipher the information extracted from the data after seeing it. We use machine learning in that scenario. The need for machine learning is growing as a result of the large number of datasets that are available. Machine learning is used in many industries to retrieve pertinent data.

Learning from the data is the aim of machine learning. How to teach robots to learn without explicit programming has been the subject of numerous studies.Numerous mathematicians and programmers use a variety of techniques to solve this problem, which involves large data sets [4]. ML techniques like support vector machines (SVM), decision trees, and random forests are commonly used for classifying dental data, with applications in age and gender estimation.

Artificial Intelligence (AI) offers numerous enhancements for forensic dentistry, including:

- **Dental Identification**: AI aids in analyzing dental images like radiographs, assisting in identifying and matching individuals based on dental features.
- **Age and Sex Estimation**: AI helps estimate individuals' age and sex through dental image analysis.
- **Facial Reconstruction**: AI generates 3D models of teeth and jaws, useful for reconstructing faces of unidentified remains.
- **Bite Mark Analysis**: AI facilitates analysis and matching of bite marks for criminal evidence.
- **Dental Databases**: AI enhances search and match capabilities in dental databases, supporting identification efforts.
- **Chatbots**: AI-driven chatbots answer questions and provide forensic dentistry education.
- **Task Automation**: AI automates dental image analysis, improving efficiency and accuracy by reducing manual effort [5].

Deep Learning (DL): The deep learning technique is a method of machine learning wherein deep neural networks, such convolutional neural networks, can process input images directly and produce the desired output without requiring the completion of intermediate steps like feature extraction and segmentation. Deep neural network construction and training, however, are difficult, expensive, and time-consuming processes. Consequently, a number of methods were created that employ pre-trained deep networks to carry out the required tasks rather than creating and training deep networks from the ground up. These techniques are commonly referred to as transfer learning . Additionally, the deep learning model suggested for forensic age estimation in this study used the transfer learning approach.CNNs are especially effective in image processing tasks, such as analyzing bite marks and matching dental records in identification efforts [6].

1.3 Challenges in AI Applications for Forensic Odontology

New technologies, particularly 3D imaging, are transforming forensic dentistry by advancing antemortem records and enabling digital 3D models of dental arches to replace traditional impressions. These digital models, derived from optical impressions, are now common in dental practices and valuable for forensic identification. Computed tomography (CT) is widely used across dental specialties, providing detailed internal and external tissue data, more comprehensive than surface scans. Recently, AI technologies like deep learning and neural networks have been explored in forensic odontology to enhance identification by automating pattern recognition and reducing human subjectivity. While promising, AI still requires expert oversight and extensive research before full implementation in forensic casework.Challenges include dataset variability, insufficient training data across diverse populations, and ethical issues related to privacy and bias in AI models. Furthermore, the lack of standardization in dental image quality and formats complicates model training and generalizability. Addressing these challenges is essential for establishing reliable AI applications in forensic odontology [7].

MATERIAL AND METHODS

Data Sources and Search Strategy

A systematic search was conducted across multiple databases, including ELSEVIER,PubMed, Scopus etc.covering articles published from 2020 to 2024. Keywords included "AI in forensic odontology,""machine learning in dental identification,""deep learning in bite mark analysis," and "forensic dental age estimation."

Inclusion and Exclusion Criteria

Inclusion criteria:

- Studies utilizing AI techniques for forensic odontology applications.
- Published between 2020 and 2024.
- Full-text availability in English.

Exclusion criteria:

- Studies unrelated to forensic applications of odontology.
- Research on AI in general medical or non-dental forensic applications.
- Non-peer-reviewed articles.

Data Extraction and Quality Assessment

Key data extracted from each study included AI methods, sample sizes, performance metrics, and limitations. Each study was evaluated for quality using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. To ensure accuracy, two independent reviewers conducted data extraction and quality assessments.

RESULTS

From the initial search, 95 articles were identified, with 45 meeting the inclusion criteria and 8 most suitable articles were systematically reviewed. Key applications in the reviewed studies included:

Author	Title	Journal	Outcome
Hachem M, Mohamed A, Othayammadath A, Gaikwad J, Hassanline T.	Emerging applications of dentistry in medico-legal practice-forensic odontology	International Journal on Emerging Technologies. 2020;11(2):66-70.DOI not available	Overview of AI in forensic Odentology
Mohammad N, Ahmad R, Kurniawan A, Mohd Yusof MY..	Applications of contemporary artificial intelligence technology in forensic odontology as primary forensic identifier: A scoping review	Frontiers in artificial intelligence. 2022 Dec 6;5:104958https://doi.org/10.3389/frai.2022.1049584	Overview of AI in forensic Odentology
Ahmed O, Saleem SA, Khan AA, Daruwala S, Pettiwala A.	Artificial intelligence in forensic odontology--A review.	International Dental Journal of Students' Research. 2023 Apr 1;11(2).doi not available	Accuracy of AI in Forensic odentology
Mahesh B.	Machine learning algorithms-a review.	International Journal of Science and Research (IJSR).[Internet]. 2020 Jan;9(1):381-6.doi not available	Machine learning
Vodanović M, Subašić M, Milošević D, Galić I, Brkić H.	Artificial intelligence in forensic medicine and forensic dentistry.	The journal of forensic odonto-stomatology. 2023 Aug;41(2):30. Doi not available	Applications of AI in forensic dentistry
Ataş İ, Özdemir C, Ataş M, Doğan Y.	Forensic dental age estimation using modified deep learning neural network.	Balkan Journal of Electrical and Computer Engineering. 2022 Aug 21;11(4):298-305.http://doi.org/10.17694/bajece.1351546	Deep learning techniques
Adserias-Garriga J, Rettger J, Hostetler SD.	Principles in Identification of Human Remains through Forensic Odontology.	Perspectives in Legal and Forensic Sciences.2024 Sep;1(1):10006.**https://doi.org/10.70322/plfs.2024.10006**	Challenges of AI in dentistry

DISCUSSION

The reviewed studies provide a broad spectrum of insights into the application and effectiveness of AI in forensic odontology. Hachem et al. (2020) and Mohammad et al. (2022) give overviews of AI's role in transforming forensic odontology. Their discussions emphasize AI's potential in dental image analysis, particularly in processes related to identification, age estimation, and matching. Both studies highlight the versatility of AI tools in the forensic field, detailing how AI-based models can assist forensic odontologists in identifying individuals through automated analysis of dental radiographs and images. They emphasize AI's utility as a primary forensic identifier, focusing on its contributions to streamlined processes and enhanced accuracy. These overviews are instrumental in establishing the foundational applications of AI, illustrating its capacity to replace traditional methods with more efficient, technology-driven approaches.

Ahmed et al. (2023) delve into the accuracy and reliability of AI applications, emphasizing AI's capacity to improve forensic identification accuracy. This review considers the role of machine learning algorithms, which underpin many AI systems, in improving pattern recognition and thus, identification outcomes. By assessing specific AI models, this article explores the constraints that limited datasets and variability in dental records impose on AI's forensic accuracy. Ahmed et al. point out that standardization of dental data is critical to ensure the model's accuracy and effectiveness, calling attention to the need for unified datasets in dental records across institutions. These insights reveal how standardization could mitigate limitations in AI's performance, making it a more reliable tool for forensic odontology.

The review by Mahesh (2020) adds technical depth by providing a comparative overview of various machine learning algorithms. By breaking down each algorithm's unique strengths, the article demonstrates how algorithm selection directly influences forensic outcomes, particularly the precision of identification processes. Mahesh highlights several practical challenges, including the computational power and data complexity required for efficient algorithm performance in a forensic setting. This article emphasizes the importance of rigorous training data and model selection, which can significantly impact AI's ability to accurately process and interpret complex dental data. These considerations serve as a foundation for understanding AI model design, focusing on the prerequisites for effective machine learning in forensic applications.

Vodanović et al. (2023) discuss the practical applications of AI beyond forensic dentistry, encompassing broader uses in forensic medicine. This interdisciplinary review illustrates how AI-driven methods are being applied for dental identification, age estimation, and bite mark analysis, underscoring AI's capacity to bring objectivity and consistency to these areas. The article highlights how AI can streamline forensic workflows by automating processes like dental age estimation, which has traditionally required subjective human interpretation. Through these examples, the review showcases AI's potential to increase reliability in forensic odontology, especially in scenarios where timely analysis is critical for case resolution.

In the research by Ataş et al. (2022), deep learning technologies are examined, specifically their application to forensic age estimation. The authors explain how modified deep neural networks are being leveraged to interpret dental images with high accuracy, especially in contexts where age verification is essential for identity confirmation. Deep learning's ability to mimic the human brain's neural processing is shown to enhance pattern recognition in dental features, thereby producing reliable age estimates from dental data. This research reveals the advantages of using complex neural network models for age determination, highlighting deep learning's capacity to address the nuances of forensic identification with greater precision.

Finally, Adserias-Garriga et al. (2024) discuss the challenges associated with implementing AI in forensic odontology, pointing out both technical and ethical limitations. They address how dataset variability, limited data availability, and concerns over AI's automated nature can affect forensic reliability. The article stresses the importance of expert involvement in forensic cases, as AI alone cannot yet replace human interpretation in dental analysis. The authors suggest that while AI has made substantial advances in forensic odontology, it remains a supportive tool rather than a complete substitute for expert analysis. This article underscores the current gaps in AI capabilities, advocating for further research and refinement of AI models to meet the standards of forensic casework fully.

Together, these articles provide a comprehensive view of AI's transformative role, its current limitations, and the requirements for future developments in forensic odontology. While AI shows promise in age estimation, dental identification, and pattern recognition, there remains a strong emphasis on data standardization, expert oversight, and interdisciplinary integration to enhance the reliability and ethical application of AI in forensic settings.

Analysis of Findings

The findings indicate that AI is effectively enhancing accuracy and reducing processing times in forensic odontology. Studies demonstrate that CNNs are particularly advantageous for image-heavy applications like bite mark analysis and age estimation due to their capacity to detect subtle patterns in dental radiographs. However, the performance of AI models is sensitive to the quality and diversity of training datasets.

Challenges and Limitations

Key challenges identified include:

- Data Standardization: Variations in dental imaging quality across facilities impact model generalizability. Establishing standardized imaging protocols could improve model performance.
- Dataset Diversity: Many studies use limited datasets that may not represent diverse populations, risking biases that reduce AI's reliability across demographic groups.
- Ethical and Legal Concerns: Privacy issues arise from handling sensitive dental records, and the opaque nature of some AI models raises questions about interpretability, which is crucial for legal validation.

Future Directions

Improving AI's role in forensic odontology requires addressing these challenges through:

- Enhanced Data Collection: Large, standardized datasets across populations are necessary for robust model training.
- Hybrid AI Models: Combining ML and DL techniques, or using ensemble models, may yield more accurate and reliable results.
- Ethical AI Frameworks: Guidelines on privacy, transparency, and fairness must be established to support AI's integration into forensic practice.

CONCLUSION

AI has demonstrated substantial potential in forensic odontology, particularly in improving the accuracy and efficiency of age estimation, bite mark analysis, and post-mortem identification. The integration of AI could revolutionize forensic odontology, yet further research is needed to standardize data, mitigate biases, and address ethical issues. With continued advancements, AI could become a standard tool, aiding forensic experts in delivering more accurate and timely identifications, ultimately supporting justice and public safety.

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