

Applications and Viability of Artificial Intelligence in Forensic Odonto-Stomatology: A Narrative Review

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ABSTRACT

Artificial intelligence (AI) has established itself as an innovative tool in health and forensic sciences, with the potential to enhance the accuracy, efficiency, and standardization of expert analyses. In Forensic Dentistry, AI has been applied in various contexts, particularly in age estimation, sex determination, and human identification, utilizing techniques such as Deep Learning and convolutional neural networks. This study aimed to evaluate the applications and viability of AI in Forensic Dentistry, highlighting its impact on the quality of forensic evidence, as well as its challenges and future perspectives. This is a narrative literature review conducted in the PubMed and Virtual Health Library (VHL) databases in May 2025, using Medical Subject Headings (MeSH) descriptors. A total of 92 studies were identified, of which 36 met the inclusion criteria after screening and analysis. The findings indicate that AI demonstrates superior performance compared to traditional methods in various dental analyses, featuring high accuracy and reduced processing time. However, limitations such as small sample sizes, lack of external validation, and dependence on high-quality databases still restrict its broad clinical and forensic application. It is concluded that AI holds great potential to improve human identification methods in Forensic Dentistry. Nevertheless, its effective implementation depends on the development of studies with greater methodological robustness, standardization of protocols, and consideration of ethical and legal aspects, thereby ensuring the reliability of automated analyses.

Keywords

Artificial intelligence, Forensic dentistry, Forensic anthropology.

Introduction

Artificial intelligence (AI), a branch of computer science, seeks to replicate human cognitive mechanisms, often reducing the need for direct human intervention. Since its introduction in 1956 at Dartmouth College, AI has demonstrated significant results across

multiple fields, with particular prominence in healthcare [1].

In forensic dentistry, the application of AI represents a relevant scientific and forensic advancement, as it enables greater precision, agility, and standardization in data analysis. In the dental field, more complex artificial intelligence models are frequently used, such as deep learning networks, which can be referred to as "strong" or "deep" AI. The most commonly employed techniques include deep learning and 3D convolutional neural networks (3D CNNs).

Deep learning is a subfield that features multiple layers of artificial neurons capable of learning independently from the provided data and information [2]. These tools simulate the functioning of the human brain for decision-making, problem-solving, learning, and automated diagnosis [3-5].

The primary purpose of forensic dentistry is to assist the judiciary in criminal and humanitarian investigations through the analysis of dental structures and soft tissues. To achieve this, various methods can be utilized, including: biological profile analysis—which comprises age, sex, and ancestry estimation—the evaluation of bite mark cases, and the comparison of dental characteristics. Methods that utilize soft tissues for identification are also employed, such as palatal rugae patterns and lip print patterns (cheiloscopy). These elements are unique to each individual, making them highly reliable for identification purposes [6-8].

Technological evolution has driven the application of Artificial Intelligence (AI) across various fields of knowledge, including forensic sciences. In Forensic Dentistry, AI represents a significant breakthrough, as its computational models are capable of processing large volumes of data quickly and accurately, aiding in human identification and evidence analysis. Furthermore, AI has the potential to enhance the accuracy of these analyses and reduce the subjectivity inherent in traditional methods. Machine learning algorithms and artificial neural networks can recognize complex patterns, mitigate subjectivity, and improve the reliability of expert reports, thereby contributing to the robustness of criminal investigations. Recent studies demonstrate that AI can outperform traditional methods in terms of efficiency and accuracy in dental identification, allowing for greater standardization and the minimization of errors in the forensic process. Additionally, its implementation can optimize expert analysis time [2-4].

Objective

Given this overview, this review aims to discuss the applications and viability of AI in Forensic Dentistry, highlighting its impact on improving the quality of forensic evidence, as well as the challenges and perspectives for its adoption in identification cases and forensic practice.

Methodology

This narrative literature review was conducted in the PubMed and Virtual Health Library (VHL) databases in May 2025, utilizing Medical Subject Headings (MeSH) descriptors. Two specific search strategies were developed for each database, combining the terms 'artificial intelligence', 'forensic dentistry', and 'forensic anthropology' with the Boolean operators 'AND' and 'OR'.

The initial search yielded 92 articles (55 in PubMed and 37 in VHL). After removing duplicates, 65 studies were screened, and 36 were deemed eligible. The inclusion criteria comprised full-text articles in English published between 2010 and 2025 that addressed the application of AI in forensic dentistry. Duplicate studies and those with no mention of AI or forensic dentistry in the title, abstract, or keywords were excluded.

The selection of articles was performed considering relevance and methodological quality. The extracted information was organized into a table (Figure 1).

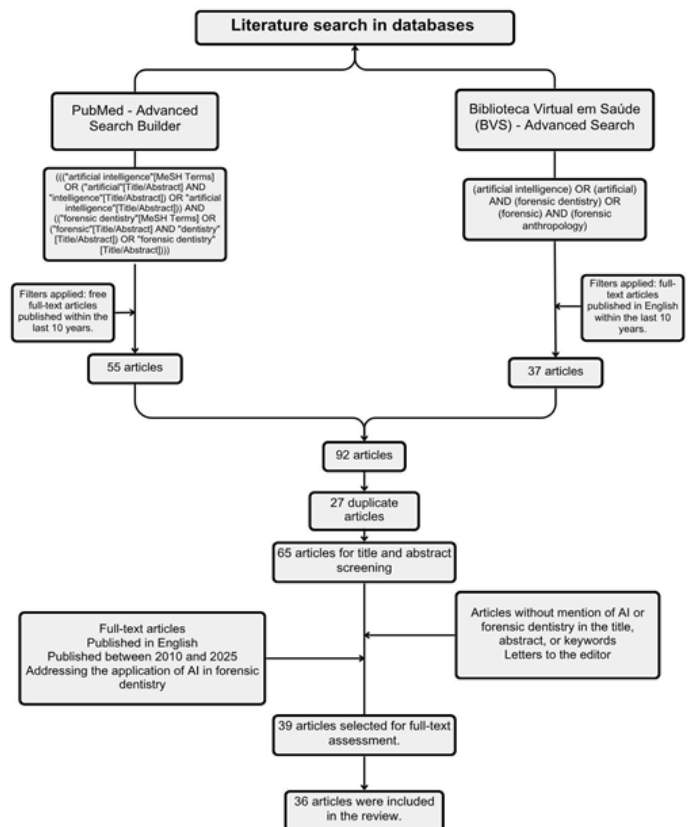


Figure 1: Flowchart of the study methodology selection process (file to be submitted separately in .jpg format).

Results

The included studies demonstrated that AI has been primarily applied in age estimation, sex estimation, and human identification, yielding promising results regarding accuracy and the reduction of analytical time. Convolutional neural networks (CNNs) and deep learning were the most frequently used methods, demonstrating superior performance compared to traditional methods in various dental analyses. Table 1 presents a comparative synthesis of the main studies, highlighting the sample size, data type, AI method employed, results, and identified limitations.

Discussion

Artificial Intelligence (AI) has demonstrated significant potential to enhance the precision, reproducibility, and efficiency of expert analyses in Forensic Dentistry. Machine learning algorithms allow for the automation of complex pattern extraction, reducing the inter-observer variability typical of traditional methods [34]. Such standardization promotes greater diagnostic consistency, especially in large volumes of radiographic images [4]. However,

Table 1: Studies on the applications and performance of Artificial Intelligence models in Forensic Dentistry.

Application	Author – Year	Sample / Data	AI Method / Algorithm	Results / Accuracy	Limitations / Observations	Study Type
Sex estimation	Hundur Hiyari et al., [9]	Panoramic radiographs	CNN (3 convolutional layers)	95,98%	Excluded edentulous radiographs; limited sample size	Experimental
	Gamulin et al., [10]	Teeth analyzed by Raman spectroscopy	SVM and RNA	RNA > 90% (molar apices)	Lower accuracy for premolars; preliminary study	Preliminary
	"Esmaeilyfard R. et al., [11]"	485 individuals (245 males, 240 females)	Naïve Bayesian (NB), Random Forest (RF), SVM, Genetic feature selection	NB: Average accuracy of 92.31%	Use of odontometric parameters (first molars) in CBCT as an additional tool	Research Article
	"Hamidi et al., [12]"	240 CBCT images (129 females, 111 males)	GADNN (Deep Learning Neural Network with Genetic Algorithm)	GADNN 86% accuracy	Optimization via evolutionary algorithm (GADNN) is a solution for higher accuracy	Research Article
Age Estimation	"De Tobel et al., [13]"	20 third molar radiographs	AlexNet (Deep Learning)	Consistent with human classification	Pilot study; small sample size	Pilot
	"Kahm et al., [14]"	Panoramic radiographs	Deep Learning (DN and WRN)	High accuracy and F1-score	Comparable to traditional methods; reduces pre-processing	Experimental
	"Pereira de Sousa et al., [15]"	Radiographs of incisors and canines	XGBoost Reg – Kvaal's method	XG Boosting > Kvaal	Better performance with machine learning	Comparative
	"Murray et al., [16]"	4,003 radiographs (augmented to 128,096)	RNA	87%	Artificially augmented sample; external validation is required	Experimental
	"Franco A. et al., [17]"	11,640 panoramic radiographs	DenseNet121 (CNN), Transfer Learning	AUC accuracy of 0.94 for males (>18 years old)	Optimal performance for classification below and above age thresholds of legal interest	Research
	"Kim, Y.-R. et al., [18]"	10,023 panoramic images	Deep Neural Network (CNN)	95.121% accuracy (tolerance ± 1.5 years)	Potential to be used as oral health education material	Research
	"Boedi M. R. et al., [19]"	CBCT scans of 99 patients (80 teeth)	Support Vector Regression (SVR), 5-part tooth segmentation (SG)	Mean error of 4.86 years ; root mean square error of 6.05 years	Complex approach, long working time (45 min/tooth), steep learning curve	Research
	"Boedi M. R. et al., [20]"	400 panoramic radiographs	CNN DenseNet201, AlexNet	Stage allocation accuracy of 0.61 (DenseNet201)	DenseNet201 improves accuracy by 3% compared to AlexNet	Research
Human identification	"Kılıc MC, et al., [21]"	421 panoramic radiographs	Faster R-CNN Inception v2 (COCO), Deep Learning	Sensitivity: 0.9804; Precision: 0.9571; F1 Score: 0.9686	Promising for the automated mapping of radiographs; useful for forensic identification	Research
	"Bui, R, et al., [22]"	456 images from France and Uganda	Mask R-CNN, U-Net (Deep Learning)	U-Net: mIoU 91.2%; Precision: 95% (13M replication)	Small datasets and challenges related to practical implementation and usability	Research / Pilot
	"Saleh, O. et al., [23]"	600 teeth	Texture-based CNN, Discrete Wavelet Transform (DWT)	Maximum accuracy: 80%; 100% accuracy for the maxillary central incisor and mandibular canine	The maxillary canine showed the lowest accuracy (32%) due to the limited number of samples	Research

	"Matsuda S. et al., [24]"	30 pairs of panoramic radiographs (30 patients)	VGG16 (CNN)	VGG16 achieved the highest accuracy (100.0%)	Very small dataset, limiting the generalizability of the findings	Research / Preliminary
	"Eto N. et al., [25]"	Intraoral scan images acquired from 34 cadavers	LeNet-based CNN with transfer learning	Overall accuracy: 0.952 (95.2%)	Improved efficiency of personal identification in large-scale disaster scenarios	Research
	"Estai et al., [26]"	591 digital OPGs (17,135 teeth)	U-Net, Faster R-CNN, VGG-16 (CNN)	Tooth detection recall/precision: 0.99 (99%); Tooth numbering F1 score: 0.98 (98%)	Useful for the automated archiving of dental records in general and forensic dentistry	Research
	"Kavousinejad, S. et al., [27]"	358 cases (pre- and post-treatment cephalograms)	K-VIN algorithm	Accuracy: 97.5%; Sensitivity: 97.7%; Specificity: 95.2%	Tested using cephalograms from living individuals; demonstrates promising potential for forensic applications	Research
	"Thurzo, A. et al., [28]"	Mandibular bone segments with treated teeth	Micro-CT, chemometrics, AI (Convolutional Neural Network)	Automated CBCT segmentation with separate STL outputs	restorations demonstrated greater resistance to sulfuric acid; 3D patterns can be used for matching with 2D dental records in forensic identification	Research / Experimental
	"Kim et al., [29]"	746 subjects (large-scale DPR dataset)	Convolutional Neural Network (CNN)	Rank-5 identification success rate: 92.23% with data augmentation	The model can generate identification candidates in approximately 3 seconds per image, demonstrating potential for rapid forensic dental identification	Research
	"Heinrich, A. et al., [30]"	43,467 panoramic radiographs (PRs) from 24,545 patients	Computer vision, Speeded Up Robust Features (SURF) algorithm	85% of individuals could be reliably identified	SURF is not suitable for detecting changes in dentition; identification is only possible when antemortem PRs are available in the database	Research
	"Choi H-R, et al., [31]"	2,058 paired DPRs from 1,029 individuals	EfficientDet-D3 modified CNN	Identification success rate: 83.2% (upper confidence limit: 20.0%); 97.2% for females	Demonstrated the feasibility of human identification considering changes in dentition over time	Research
	"S. B and N. R et al., [32]"	106 individuals (3,159 teeth)	Transfer Learning (CNN)	Classification accuracy: 100% (Stage 1); 97.5% (Molar)	The algorithm outperformed other classical algorithms	Research
	FAN et al. [33]	15,369 DPRs from 6,300 individuals	DENT-net	Rank-1 accuracy: 85.16%; Rank-5 accuracy: 97.74%	Can be used without the need for specialized equipment or advanced technical knowledge	Research

Source: Authors' own elaboration

performance remains heavily dependent on database quality, population representativeness of the samples, and external model validation—aspects that are still limited in most available forensic studies [4,35].

Deep Neural Networks (DNN) differ from conventional artificial neural networks by possessing multiple layers capable of learning directly from raw data, which explains their superiority in complex dental image recognition tasks [2,4]. Such models fit the concept of narrow artificial intelligence, being highly specialized in specific functions and not representing general human intelligence. This characteristic imposes the need for rigorous validation for each forensic application, given that strong performance on one dataset does not guarantee automatic generalization to other population contexts [2,4].

Within the scope of traditional Machine Learning, supervised algorithms such as Naïve Bayes, Support Vector Machines, and Random Forest present high accuracy when applied to odontometric and radiographic parameters [34,35]. However, reliance on human-labeled data can introduce systematic biases, particularly in forensic fields where anatomical variability is wide [36]. This factor reinforces the need for careful curation of the databases used in training forensic models.

Sex estimation constitutes one of the most consolidated applications of AI in Forensic Dentistry. Accuracy exceeding 95.98% has been demonstrated using convolutional neural networks on panoramic radiographs, highlighting the capacity of Deep Learning models to capture subtle morphological differences [9]. Similar results were observed when combining Raman spectroscopy and artificial neural networks, showing superior performance in molars [10]. Supervised models combined with genetic algorithms achieved an average precision of 92.31% [11]. Despite these high rates, restricted samples and strict selection criteria frequently inflate model performance artificially, limiting their extrapolation to real-world forensic scenarios [4].

Regarding age estimation, the advancements provided by AI are consistent. Deep Learning architectures can achieve performance comparable to human specialists [13,14], while XG Boosting showed superiority compared to the classical Kvaal method [15]. Artificial image augmentation enabled the training of large-scale neural networks, achieving 87% accuracy [16]. However, the absence of independent external validation in these models can compromise the generalization of results, especially when there is extensive use of data augmentation [4].

Deep architectures such as DenseNet121 applied to large databases of panoramic radiographs achieve high accuracy for age groups of legal interest [17]. Deep networks validated using cross-validation techniques and three-dimensional CBCT data using support vector regression obtained reduced mean errors [18,19]. These studies indicate a progressive transition toward volumetric analyses closer to real anatomy, although still limited by computational costs and clinical-forensic processing time [4].

In human identification, CNN-based systems have shown remarkable performance. Maximum accuracy has been obtained using VGG16 in controlled datasets [24], while the DENT-net system achieved high success rates in extensive radiograph databases [33]. The K-VIN algorithm applied to digital cephalograms displayed high sensitivity and specificity in individual identification [27]. However, these systems remain heavily dependent on the existence of standardized, high-quality antemortem records [4].

Although complementary techniques such as palatal rugoscopy and lip print analysis are mentioned as potential identification tools, relevant limitations exist regarding the standardization, reproducibility, and population validation of these methods, which warrants caution in their incorporation into automated AI-based systems [4].

AI algorithms frequently outperform conventional approaches in specific dental classification and prediction tasks [2,4,34]. Nevertheless, the predominance of controlled experimental studies with limited samples and a lack of multicenter validation restricts the immediate application of these systems in routine forensic casework [2,4,34].

Ethical and legal challenges associated with AI also prove to be central. High statistical accuracy is insufficient to guarantee the legal reliability of automated forensic evidence, making transparency and auditability of algorithmic processes indispensable [1]. Explainable Artificial Intelligence (XAI) allows for the identification of which anatomical features ground the models' decisions, favoring evidence traceability, technical adversarial debate, and compliance with digital evidence preservation standards, such as ABNT NBR ISO/IEC 27037 [1].

Finally, the strengthening of national databases, the standardization of image acquisition protocols, and robust external validation of models constitute essential steps for the consolidation of AI in Forensic Dentistry [4,15,33]. The integration of explainable systems, combined with appropriate technological infrastructure and interdisciplinary training for forensic experts, represents the safest path toward incorporating these tools into judicial practice [4].

Conclusion

Artificial Intelligence demonstrates great potential to enhance human identification, age estimation, and sex determination methods in Forensic Dentistry. Despite the promising results, robust external validations, standardization of protocols, and adequate technological infrastructure are still required for its full implementation. The advancement of explainable AI and the encouragement of interdisciplinary research are fundamental to ensuring the ethical and legal reliability of automated analyses.

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