Vol. 1, No. 1, pp. XXV-XXXIII | 2023
www.cfosrjprocedia.usim.edu.my
CFORSJ i-CONF Proceedings

ARTIFICIAL INTELLIGENCE AS SUPPORTING METHODS IN FORENSIC DENTAL IDENTIFICATION

KECERDASAN BUATAN SEBAGAI METOD SOKONGAN DALAM IDENTIFIKASI FORENSIK GIGI

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ABSTRACT

Forensic dental identification, a critical facet of medico-legal investigations, is experiencing a paradigm shift with the integration of artificial intelligence (AI). This paper examines the role of AI as a supporting method in forensic dental identification, elucidating its impact on accuracy, efficiency, and collaborative potential. This article provides an overview of AI tools applied in forensic dental contexts, detailing their contributions to streamlining identification processes and improving precision. Real-world case studies illustrate successful outcomes facilitated by AI, demonstrating its efficacy in addressing complex forensic challenges. As forensic science embraces the capabilities of AI, this paper contributes to the evolving discourse by providing a comprehensive understanding of the transformative impact of AI in forensic dental identification. It serves as a foundation for further research, ethical deliberations, and advancements in leveraging AI to enhance the accuracy and efficiency of forensic investigations.

Keywords: *artificial intelligence, forensic dentistry, human identification, legal identity*

Introduction

Forensic odontology, a specialized branch of forensic science, is crucial in human identification by examining dental remains. Traditional methods of forensic dental identification rely heavily on the expertise of forensic odontologists, who manually compare dental records with postmortem dental findings. As the demand for accurate and efficient identification processes continues to grow, there is a pressing need for innovative technologies to complement and enhance traditional forensic methods (Avon 2004; Pramod et al. 2012; Verma et al. 2014).

In recent years, the ascendancy of artificial intelligence (AI) has significantly impacted diverse scientific domains, presenting a paradigm shift with the potential to revolutionize conventional forensic practices. Notably, within the specialized field of forensic odontology, AI has emerged as a transformative force, affording a distinctive prospect to enhance and streamline the identification process through sophisticated pattern recognition, data analysis, and machine learning methodologies (Bewes et al. 2019; Mohammad et al. 2022; Vila-Blanco et al. 2023). This article explores the incorporation of artificial intelligence (AI) as a supplementary technique in forensic dental identification. Its objective is to illuminate the collaboration between human expertise and AI to achieve forensic outcomes that are more precise, efficient, and dependable.

Literature Review

Human Identification and Forensic Odontology

Forensic human identification, at its core, operates on the fundamental principle of utilizing diverse scientific methodologies to ascertain an individual's identity, particularly in scenarios where traditional means of identification are unattainable. The significance of this process reverberates through legal, medical, and humanitarian domains. Central to the discipline is the practice of Dental Identification, where forensic odontology emerges as a pivotal player, employing the scrutiny of dental records and postmortem findings to establish identity, particularly in instances where visual identification proves impracticable. A holistic approach is imperative in this identification endeavour, necessitating careful consideration of all available scientific and contextual evidence, ranging from dental and DNA data to other pertinent information. Collaboration lies at the heart of forensic human identification, involving a multidisciplinary alliance encompassing forensic odontologists, pathologists, anthropologists, and biochemists. This collaborative synergy ensures a thorough analysis of the evidence at hand. Beyond its role in identity confirmation, forensic odontology contributes significantly to the determination of the biological profile of an individual, encompassing factors such as age, sex, and race. The ultimate goal of this multifaceted process is to provide closure to the bereaved families, facilitate the issuance of death certificates, and meet legal requirements. Forensic human identification embodies a multidisciplinary approach, employing diverse scientific methods and evidence to establish identity, serving the overarching purposes of legality, medicine, and humanity. This intricate process relies on the expertise of forensic odontologists and other specialists to ensure meticulous and accurate identifications (Wagner 2010; Berketa et al. 2012; Ata-Ali and Ata-Ali 2014; Knott 2016).

Forensic odontology is a subspecialty of dentistry that focuses on identifying deceased persons, often by analyzing dental records and postmortem findings. It plays a crucial role in various legal and medical contexts, such as criminal and civil cases, mass disasters, and terrorist attacks (Verma et al. 2014; Krishan et al. 2015; Jeddy et al. 2017). The fundamental tenets of forensic odontology encapsulate diverse facets, including dental identification, age estimation, sex determination, and bitemark analysis. The discipline also encompasses the meticulous handling of dental evidence, involving the proper examination, preservation, and presentation of dental evidence in legal proceedings. Being inherently multifaceted, forensic odontology necessitates collaboration with a cadre of experts, including forensic pathologists, anthropologists, and serologists. This collaborative approach ensures a comprehensive analysis of dental evidence. Furthermore, forensic odontology has evolved into an integral component of prominent international forensic education programs, playing a pivotal role in the identification of

human remains across diverse scenarios, including natural disasters, accidents, and acts of terrorism (Clark 1993; Avon 2004; Carabott 2013; Nadil et al. 2019).

Brief Introduction to Artificial Intelligence (AI)

Artificial Intelligence (AI) is a method of creating computers, software, or robots that can think intelligently like the human mind. It involves studying the patterns of the human brain and analyzing cognitive processes to develop intelligent software and systems. AI has become integral to our daily lives, revolutionizing various industries and enhancing user experiences. Some notable examples of AI applications include chatbots, virtual assistants, and real-time navigation systems. AI systems are designed to focus on critical tasks and make better decisions based on acquired data related to a use case. They can be used for complex problem-solving, pattern recognition, and decision-making processes. AI techniques are derived from probability theory, economics, and algorithm design, and the field draws upon computer science, mathematics, psychology, and linguistics (Ertel 2017).

In the realm of artificial intelligence (AI), several crucial concepts and terms deserve attention (Mohammad et al. 2022):

1. Machine Learning, a subset of AI, focuses on creating algorithms that can learn from data and continuously enhance their performance over time. This dynamic process allows systems to adapt and improve without explicit programming.
2. Deep Learning, a branch of Machine Learning, utilizes artificial neural networks to emulate the intricate learning mechanisms of the human brain. This sophisticated approach involves interconnected nodes that process inputs and generate outputs, resembling the neural connections in the human cognitive framework.
3. Neural Networks, as computational models, take cues from the complex structure and functions of the human brain. These networks consist of interconnected nodes that collaboratively process inputs and produce corresponding outputs, mirroring the parallelism found in the human neural architecture.
4. Reinforcement Learning, another machine learning dimension, involves identifying optimal behavior within a specific environment. This is accomplished by the system's ability to learn from rewards and penalties, refining its decision-making processes through past experiences. These fundamental concepts collectively outline the building blocks of AI, paving the path for ongoing advancements that consistently push the boundaries of intelligent systems.

Application of AI in Forensic Dental Identification

Artificial Intelligence (AI) stands poised as a transformative tool in forensic dentistry, potentially elevating the precision and efficiency of dental identification processes. In this context, AI serves as a valuable ally for forensic dentists by facilitating the analysis of dental images, including radiographs, enabling the identification and correlation of individuals based on their dental characteristics. Leveraging machine learning algorithms, AI can sift through vast datasets, holding promise, particularly in dental caries diagnosis, fueled by the growing repository of dental images. Forensic odontology, benefiting extensively from AI, employs this technology in various applications, ranging from bitemark identification to predicting mandibular morphology, gender determination, and age estimation (Mohammad et al. 2022). As AI continues to make strides, its integration into routine dental practices is expected to burgeon, with an increasing number of dental clinics, hospitals, and educational institutions embracing these innovative technologies. Despite these advancements, it is crucial to note that the application of AI in forensic dentistry is still in its nascent stages. Ongoing research endeavors and practical implementations in real-life scenarios are imperative to unlock AI's full spectrum of benefits in this field (Anil et al. 2023; Ahmed et al. 2023; Vodanović et al. 2023; Katsumata 2023).

Forensic odontology may necessitate the use of either a visual or clinical approach for identification purposes. Occasionally, forensic professionals may need to rely on established methods to identify individuals, such as using the atlas to estimate dental age. Nevertheless, the current technology can be a complex process for a large-scale incident that necessitates a more significant number of forensic identifications, especially in the context of mass disasters. Many specialists have resorted to implementing automation in their current profession to enhance efficiency.

Bitemark Analysis

Human bitemark analysis is a forensic method that identifies an attacker by comparing their dental impressions to the teeth marks on a victim's skin or other surfaces. Bitemark analysis is based on the premise that every individual possesses a particular and exclusive arrangement of teeth, resulting in a correspondingly unparalleled pattern or impression following a bite. Bitemark analysis has been utilized for purposes such as personal identification, medico-legal evaluation of oral tissue injuries, and providing expert testimony regarding dental negligence. Nevertheless, the scientific basis of bitemark analysis has been scrutinised, and research has demonstrated that the precision and dependability of bitemark identification are lacking. NIST has thoroughly evaluated the scientific underpinnings of bitemark analysis and determined that it lacks an adequate scientific basis. Although bitemark analysis has many limits, it has traditionally been acknowledged as a dependable scientific technique, and testimony regarding the analysis has generally been accepted after appropriate verification and confirmation (Verma et al. 2013; Saks et al. 2016).

Artificial Intelligence (AI) can significantly improve bite mark analysis in forensic dentistry through various means. AI can be employed to enhance images, facilitating the analysis of bite marks by forensic dentists and enabling the identification of patterns and distinctive characteristics. Additionally, it can be utilized to compare bite marks, assisting in identifying possible culprits. Moreover, AI can be employed to scrutinize dental photographs, assisting forensic dentists in approximating the age and gender of persons, which can be especially advantageous when the person's identification is unidentified (Ahmed et al. 2023; Vodanović et al. 2023). The utilization of AI in examining bite marks has exhibited encouraging outcomes, as research has showcased exceptional precision and the ability to reduce human prejudice. An example is the application of artificial neural networks (ANN) in the analysis of bite marks, which has demonstrated a high level of precision. The objective of computer-aided analysis is to reduce human bias to a minimum (Ahmed et al. 2023).

Mahasantipiya et al. (2012) conducted an initial investigation on applying artificial neural networks (ANN) in bite mark detection. The project aims to create a machine-learning model that achieves high accuracy and addresses any potential biases introduced by human analysis. The inclusion requirements stipulate that individuals must not have any missing lower or upper anterior teeth, nor should they have any fixed orthodontic appliances. Subsequently, samples of bite marks are gathered using conventional dental wax in five distinct biting positions. The digital camera was used to capture the bite marks of these samples before using the preprocessing method. The learning procedure was applied to the selected features of the bite marks using the proposed ML model. This study demonstrates that the trained networks exhibited high accuracy in matching. Despite the relatively low accuracy of the suggested artificial neural network (ANN), it demonstrates the potential of this method and warrants more investigation to enhance its performance. Additionally, the scientists proposed enhancing the ML model's training by incorporating other properties of the bite marks, which could potentially improve its performance (Mahasantipiya et al. 2011).

Sex Determination

Sex determination is a crucial component of forensic identification, particularly in cases where information about the deceased is not accessible. Forensic odontologists can aid in ascertaining the gender of remains by analyzing dental and cranial characteristics. Different attributes of teeth, such as shape, size of the visible part, and length of the part embedded in the jaw, distinguish males and females.

Forensic odontologists can utilize disparities in skull patterns and characteristics between males and females to determine the sex of the remains. Sex determination can be achieved by analyzing the DNA recovered from the remains using molecular techniques. Sex estimate techniques can be categorized into non-metric and metric methods. Non-metric methods rely on the presence or lack of morphological traits, whereas metric methods include measuring specific aspects of the skull or teeth. Optimal means of ascertaining an individual's sex involve employing a blend of characteristics, as singular attributes may not consistently reflect the individual's sex (Nagare et al. 2018; Piprek 2020; Okkesim and Sezen Erhamza 2020).

Artificial intelligence (AI) has been utilized for sex determination, specifically in forensic and medical settings. Machine learning algorithms, a subset of artificial intelligence, have been employed to accurately assess the sex of an individual based on the shape and structure of their skull in the field of forensic sex determination (Bewes et al. 2019; Kondou et al. 2023). Artificial neural networks have demonstrated a 95% accuracy in determining the sex of skeletal structures. This implies their ability to mitigate potential biases that humans may introduce when estimating the sex of skeletal remains. The AI models have undergone training using diverse datasets, encompassing CT pictures and dental measures. They have demonstrated encouraging outcomes in accurately guessing the sex of individuals for forensic applications. Additionally, AI has been used for fetal sex determination, presenting a viable model for providers in medical settings (Toy et al. 2022; Frisch et al. 2023; Anic-Milosevic et al. 2023).

Akkoç et al. (2016) suggested a completely automated method for determining the sex of individuals based on photographs of their maxillary dental plaster models. Before the segmentation and classification stage, the image capture process occurs. Initially, a conventional image is acquired by stabilizing the camera position above the mechanism and outfitting it with light sources structured like cubes to capture light from all orientations. Channel B of the standard image has prominent characteristics compared to the other color channels, as determined by the RGB color model. Image segmentation involves turning a colored image into a binary image and then performing morphological operations such as binary dilation and erosion. Ultimately, the segmented plaster picture is converted into a gray-level image to extract features using the gray-level co-occurrence matrix (GLCM) approach. The extracted features are subsequently categorized using the Random Forest method. The results indicate that the RF algorithm achieves the highest level of classification accuracy when compared to other approaches such as SVM, ANN, and kNN (Akkoç et al. 2016).

Dental Age Estimation

Dental age estimation is a critical procedure in forensic identification used to determine an individual's age in the absence of formal birth records. This approach is based on a reference dataset comprising dental panoramic tomographs (DPT), which contain images of various types of tooth morphology. The characteristics utilized for measuring dental age include tooth growth, biochemical factors, and postformation changes. Various approaches, such as clinical, radiographic, histological, and biochemical techniques, are employed for this goal. Dental age estimation is crucial in identifying individuals affected by natural catastrophes and is particularly valuable when alternative identifying procedures, such as visual identification and fingerprinting, are not feasible. Radiographic techniques, particularly those relying on tooth developmental alterations, are extensively employed for dental age assessment and are regarded as more precise owing to their suitability for living and deceased individuals. Multiple techniques exist for estimating the age of deceased or living individuals, each with different levels of precision. These include physical examination, radiography of the left hand, and dental examinations. The precision of the outcomes derived from age estimation relies on the methodology used, and the advancement of novel algorithms and regression functions seeks to enhance the precision of dental age determination (Limdiwala and Shah 2013; Puranik and Uma 2015; Lewis and Senn 2015; Verma et al. 2019).

The use of AI for dental age estimation has been growing. AI can be employed to analyze dental images, assisting forensic dentists in accurately determining the age of individuals. This is especially valuable

in situations where the individual's identity is unidentified. Several studies have showcased the capability of AI technology, namely deep learning neural networks, to automate the task of dental age assessment. This has resulted in enhanced precision and effectiveness. The utilization of AI in forensic odontology has demonstrated encouraging outcomes in age estimate, representing a significant advancement in the discipline by providing a more uniform and dependable methodology. Nevertheless, the application of AI in forensic dental age estimation is now in a state of development, and additional study is required to assess and enhance the precision and dependability of these AI-driven techniques. AI technology aims to enhance the precision of dental age estimation in forensic identification by creating novel algorithms and regression functions (Bjelopavlovic et al. 2022; Pintana et al. 2022; Kahm et al. 2023).

AI technology enhances the precision of dental age estimation by examining dental photos, such as x-rays, to determine an individual's age by assessing the growth and deterioration of their teeth. AI systems can be trained to identify and analyze patterns and characteristics related to dental growth, resulting in more precise age prediction. AI techniques, specifically deep learning neural networks, can automate estimating dental age, enhancing efficiency and quicker processing durations. Utilizing AI in dental age estimation can mitigate the heterogeneity resulting from the practitioner's knowledge and expertise, yielding more uniform outcomes. In addition, AI technology has the capability to offer a more consistent and dependable method for estimating dental age. This is because it can be programmed to identify and analyze the patterns and characteristics related to tooth growth. The aforementioned-benefits render AI-based techniques an auspicious instrument for dental age estimation in forensic identification (Kim et al. 2021; Wu et al. 2022; Mohammad et al. 2022; Aljameel et al. 2023; Vila-Blanco et al. 2023).

Conclusion

The utilization of AI in forensic dental identification holds significant promise to enhance the precision and effectiveness of the identification procedure. Nevertheless, additional investigation and tangible application are imperative to actualize the advantages of AI in this domain properly. Forensic dentists can improve their investigative skills and make forensic practices more effective and efficient by adopting and utilizing AI technology and its possibilities.

Conflict of Interest

The author declares no conflict of interest in publishing this article.

Acknowledgment

Nil.

References

Ahmed O, Saleem SA, Khan AA, Daruwala S, Pettiwala A (2023) Artificial intelligence in forensic odontology – A review. International Dental Journal of Student's Research 11(2):54–60. https://doi.org/10.18231/j.idjsr.2023.012

Akkoç B, Arslan A, Kök H (2016) Gray level co-occurrence and random forest algorithm-based gender determination with maxillary tooth plaster images. Comput Biol Med 73:102–107. https://doi.org/10.1016/j.compbiomed.2016.04.003

Aljameel SS, Althumairy L, Albassam B, Alsheikh G, Albluwi L, Althukair R, Alhareky M, Alamri A, Alabdan A, Shahin SY (2023) Predictive Artificial Intelligence Model for Detecting Dental Age Using Panoramic Radiograph Images. Big Data and Cognitive Computing 7(1):8. https://doi.org/10.3390/bdcc7010008

Anic-Milosevic S, Medancic N, Calusic-Sarac M, Dumancic J, Brkic H (2023) Artificial neural network model for predicting sex using dental and orthodontic measurements. Korean J Orthod 53(3):194–204. https://doi.org/10.4041/kjod22.250

Anil S, Porwal P, Porwal A (2023) Transforming Dental Caries Diagnosis Through Artificial Intelligence-Based Techniques. Cureus 15(7):e41694. https://doi.org/10.7759/cureus.41694

Ata-Ali J, Ata-Ali F (2014) Forensic dentistry in human identification: A review of the literature. J Clin Exp Dent 6(2):e162-7. https://doi.org/10.4317/jced.51387

Avon SL (2004) Forensic odontology: The roles and responsibilities of the dentist. J Can Dent Assoc (Tor)

Berketa JW, James H, Lake AW (2012) Forensic odontology involvement in disaster victim identification. Forensic Sci Med Pathol 8(2):148–156. https://doi.org/10.1007/s12024-011-9279-9

Bewes J, Low A, Morphett A, Pate FD, Henneberg M (2019) Artificial intelligence for sex determination of skeletal remains: Application of a deep learning artificial neural network to human skulls. J Forensic Leg Med 62:40–43. https://doi.org/10.1016/j.jflm.2019.01.004

Bjelopavlovic M, Zeigner A-K, Hardt J, Petrowski K (2022) Forensic Dental Age Estimation: Development of New Algorithm Based on the Minimal Necessary Databases. J Pers Med 12(8):1280. https://doi.org/10.3390/jpm12081280

Carabott R (2013) Brief introduction to forensic odontology. In: Forensic Odontology. John Wiley & Sons, Ltd, Chichester, UK, pp 1–8

Clark DH (1993) Practical Forensic Odontology. Medico-Legal Journal 61(2):114–114. https://doi.org/10.1177/002581729306100208

Ertel W (2017) Introduction to Artificial Intelligence. Springer International Publishing, Cham

Frisch EH, Malshe A, Duhaime EP, Jain A, Allen R, Corey S, Fischetti CE (2023) Artificial intelligence for fetal sex determination. Am J Obstet Gynecol 228(1):S462. https://doi.org/10.1016/j.ajog.2022.11.799

Jeddy N, Ravi S, Radhika T (2017) Current trends in forensic odontology. J Forensic Dent Sci. https://doi.org/10.4103/jfo.jfds_85_16

Kahm SH, Kim J-Y, Yoo S, Bae S-M, Kang J-E, Lee SH (2023) Application of entire dental panorama image data in artificial intelligence model for age estimation. BMC Oral Health 23(1):1007. https://doi.org/10.1186/s12903-023-03745-x

Katsumata A (2023) Deep learning and artificial intelligence in dental diagnostic imaging. Japanese Dental Science Review 59:329–333. https://doi.org/10.1016/j.jdsr.2023.09.004

Kim S, Lee Y-H, Noh Y-K, Park FC, Auh Q-S (2021) Age-group determination of living individuals using first molar images based on artificial intelligence. Sci Rep 11(1):1073. https://doi.org/10.1038/s41598-020-80182-8

Knott S (2016) Human identification. In: Taylor JA, Kieser JA (eds) Forensic Odontology. John Wiley & Sons, Ltd, Chichester, UK, pp 167–184

Kondou H, Morohashi R, Kimura S, Idota N, Matsunari R, Ichioka H, Bandou R, Kawamoto M, Ting D, Ikegaya H (2023) Artificial intelligence-based forensic sex determination of East Asian cadavers from skull morphology. Sci Rep 13(1):21026. https://doi.org/10.1038/s41598-023-48363-3

Krishan K, Kanchan T, Garg AK (2015) Dental Evidence in Forensic Identification – An Overview, Methodology and Present Status. Open Dent J 9(1):250–256. https://doi.org/10.2174/1874210601509010250

Lewis JM, Senn DR (2015) Forensic Dental Age Estimation: An Overview. J Calif Dent Assoc 43(6):315–319. https://doi.org/10.1080/19424396.2015.12222856

Limdiwala P, Shah J (2013) Age estimation by using dental radiographs. J Forensic Dent Sci 5(2):118. https://doi.org/10.4103/0975-1475.119778

Mahasantipiya P, Yeesarapat U, Suriyadet T, Sricharoen J, Dumrongwanich A, Thaiupathump T (2011) Bitemark Identification Using Neural Networks: A Preliminary Study. In: Proceedings of the International MultiConference of Enginieers and Computer Scientists 2011. Hong Kong

Mohammad N, Ahmad R, Kurniawan A, Mohd Yusof MYP (2022) Applications of contemporary artificial intelligence technology in forensic odontology as primary forensic identifier: A scoping review. Front Artif Intell 5. https://doi.org/10.3389/frai.2022.1049584

Nadil A, Shanavas A, George Baby G, Alex Daniel V, Mary JG, Alex V (2019) Role of Antemortem Data in Forensic Odontology: A Literature Review. https://doi.org/10.4103/ijfo.ijfo_19_19

Nagare SP, Chaudhari RS, Birangane RS, Parkarwar PC (2018) Sex determination in forensic identification, a review. J Forensic Dent Sci 10(2):61–66. https://doi.org/10.4103/jfo.jfds_55_17

Okkesim A, Sezen Erhamza T (2020) Assessment of mandibular ramus for sex determination: Retrospective study. J Oral Biol Craniofac Res 10(4):569–572. https://doi.org/10.1016/j.jobcr.2020.07.019

Pintana P, Upalananda W, Saekho S, Yarach U, Wantanajittikul K (2022) Fully automated method for dental age estimation using the ACF detector and deep learning. Egypt J Forensic Sci 12(1):54. https://doi.org/10.1186/s41935-022-00314-1

Piprek RP (2020) History of The Research on Sex Determination. Biomed J Sci Tech Res 25(3). https://doi.org/10.26717/BJSTR.2020.25.004194

Pramod JB, Marya A, Sharma V (2012) Role of forensic odontologist in post mortem person identification. Dent Res J (Isfahan) 9(5):522–530

Puranik M, Uma SR (2015) Dental Age Estimation: A Review. Journal of Dental and Maxillofacial Research 1(12):24. https://doi.org/10.31038/jdmr.2018114

Saks MJ, Albright T, Bohan TL, Bierer BE, Bowers CM, Bush MA, Bush PJ, Casadevall A, Cole SA, Denton MB, Diamond SS, Dioso-Villa R, Epstein J, Faigman D, Faigman L, Fienberg SE, Garrett BL, Giannelli PC, Greely HT, Imwinkelried E, Jamieson A, Kafadar K, Kassirer JP, Koehler J "Jay," Korn D, Mnookin J, Morrison AB, Murphy E, Peerwani N, Peterson JL, Risinger DM, Sensabaugh GF, Spiegelman C, Stern H, Thompson WC, Wayman JL, Zabell S, Zumwalt RE (2016) Forensic bitemark identification: weak foundations, exaggerated claims. J Law Biosci 3(3):538–575. https://doi.org/10.1093/jlb/lsw045

Toy S, Secgin Y, Oner Z, Turan MK, Oner S, Senol D (2022) A study on sex estimation by using machine learning algorithms with parameters obtained from computerized tomography images of the cranium. Sci Rep 12(1):4278. https://doi.org/10.1038/s41598-022-07415-w

Verma AK, Kumar S, Bhattacharya S (2013) Identification of a person with the help of bite mark analysis. J Oral Biol Craniofac Res 3(2):88–91. https://doi.org/10.1016/j.jobcr.2013.05.002

Verma AK, Kumar S, Rathore S, Pandey A (2014) Role of dental expert in forensic odontology. Natl J Maxillofac Surg 5(1):2–5. https://doi.org/10.4103/0975-5950.140147

Verma M, Verma N, Sharma R, Sharma A (2019) Dental age estimation methods in adult dentitions: An overview. J Forensic Dent Sci 11(2):57–63. https://doi.org/10.4103/jfo.jfds_64_19

Vila-Blanco N, Varas-Quintana P, Tomás I, Carreira MJ (2023) A systematic overview of dental methods for age assessment in living individuals: from traditional to artificial intelligence-

based approaches. Int J Legal Med 137(4):1117–1146. https://doi.org/10.1007/s00414-023-02960-z

Vodanović M, Subašić M, Milošević DP, Galić I, Brkić H (2023) Artificial intelligence in forensic medicine and forensic dentistry. J Forensic Odontostomatol 41(2):30–41

Wagner G (2010) Scientific Methods of Identification. In: Forensic Dentistry

Wu T-J, Tsai C-L, Gao Q-Z, Chen Y-P, Kuo C-F, Huang Y-H (2022) The Application of Artificial-Intelligence-Assisted Dental Age Assessment in Children with Growth Delay. J Pers Med 12(7):1158. https://doi.org/10.3390/jpm12071158