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Artificial Intelligence–Driven Innovations in Forensic Odontology for Human Identification: A Narrative Review

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Abstract: Forensic odontology is a branch of forensic science that plays a role in identification, including age and sex estimation. The identification results acted as valid evidence based on the science of forensic dentistry, which is used in the judicial process. Traditional methods of identification have the disadvantage of subjectivity on the part of the examiner. The analysis results can be biased, leading to incorrect conclusions. The rapid development of technology has impacted the field of forensic odontology. This review aimed to evaluate the potential and applications of AI in forensic odontology. Artificial intelligence (AI) is a computer-based system designed using principles of human intelligence. The application of artificial intelligence to assist forensic experts is growing and being explored increasingly. Artificial intelligence in forensic odontology plays a role in gender determination, age estimation, lip print analysis, toothmark analysis, personal identification, and facial reconstruction. The AI-based identification process is expected to eliminate the researcher's subjectivity and improve the accuracy of the results. In conclusion, artificial intelligence (AI) has significantly influenced forensic odontology by supporting key forensic tasks, including age estimation, sex determination, cheiloscopy analysis, and facial reconstruction.
Keywords: forensic odontology; artificial intelligence; identification process; application

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Introduction

Forensic odontology is a significant part of forensic science that plays a role in the identification process of the living and the dead. The scope of forensic odontology includes the examination, evaluation, management, and presentation of dental evidence used in criminal and legal proceedings to achieve justice.[1,2]

As the digital age advances, forensic dentistry is experiencing the impact of these developments. Digital developments can effectively and appropriately replace traditional forensic examinations to analyze and report the evidence. Digital forensics has advantages in mass disaster situations, individual identification, age estimation, and communication with other forensic odontologists,[1,2]

Artificial intelligence (AI) is a result of technological development.[1] It is a computer-based process that aims to produce at least partial human or animal intelligence. Moreover, it has applications in broader fields such as machine learning, speech processing, and robotics,[3,4] and involves programming computers to perform tasks that require human thinking.[5] Artificial intelligence, sometimes called intelligent machines, is intelligence demonstrated by machines. Some of the capabilities being developed are speech recognition, learning, planning, and problem-solving.[5,6]

This review aims to consider the potential and application of technological developments, namely artificial intelligence, in forensic odontology. It also examines the development of artificial intelligence in forensic dentistry.

Artificial Intelligence in Medicine

Artificial intelligence first gained acceptance after the invention of robots. Nowadays, artificial intelligence is considered as a branch of engineering that develops new concepts and solutions to address complex challenges. With the development of software programs, electronic speed, and computers, their capacity will one day be as intelligent as humans.[7] Artificial intelligence is used in the decision-making process. The system can help non-specialists obtain expert-level information.[6]

In the medical field, the use of AI falls into two branches: virtual and physical. The AI used in the virtual branch is based on machine learning and deep learning, which are mathematical algorithms that improve their capabilities through training.[7] Machine learning is a subset of artificial intelligence that uses algorithms to predict outputs or outcomes from data sets, and aims to make it easier for machines to learn from data and to solve problems.[6,8] There are several types of machine learning, namely unsupervised (able to search for patterns on its own), supervised (methods that provide algorithms from multiple pre-existing samples to classify and predict), and reinforcement learning (techniques that give reward and punishment mechanisms to form an operating strategy in a particular problem space). In medicine, this method is used to identify DNA variations, such as SNPs, to predict diseases and their derivatives using evolutionary algorithms, which are more recent and more error-prone due to the large number of parameters used for observation.[7] A neural network is a collection of algorithms that generate signals through artificial neurons. The aim is to create a neural network that works like a human brain. Deep learning is a part of machine learning that uses a network of different computational layers within a neural network to analyze data. The goal of deep learning is to build a network of neurons that automatically recognizes patterns and refines the features used to identify the next task.[8]

The second branch of the use of AI in the medical world is the physical branch. This includes physical objects, medical devices, and the growing use of robots in robotic care (carebots). The most promising is the use of robots as caregivers. Some robots are already being used as surgical assistants.[7]

Artificial Intelligence in Forensic Odontology

Using AI in dentistry is designed to help make diagnoses more accurate and efficient. Artificial intelligence is an interconnected set of data on a computer processor that is inspired by

the human nervous system. Dentists worldwide will be able to connect through this network.[6] Technological developments, in particular the use of artificial intelligence in the process of analysis and problem solving in forensic odontology, are also having an impact on the field of forensic odontology.[8] Dental professionals have an essential role to play in identifying people for action because of child abuse, crime, sexual abuse, ill-treatment, and other legal issues.[8,9]

Artificial intelligence in forensic dentistry aims to train, decide, and solve forensic identification problems, such as diagnosing teeth and oral diseases.[9] In addition, lip prints, teeth, palatal ridges, jawbones, and dental radiographs are considered possible methods of individual identification.[9,10] This AI is used in dentistry for age estimation, sex determination, facial reconstruction, lip print analysis, and 3D printing.[5,9]

Age Estimation

Forensic medical image interpretation is typically performed by experts such as radiologists and dentists. Age estimation is generally based on the developmental stage of the anatomical structures shown in the figure.[11] To date, age estimation using machine learning algorithms is increasing over time. The development of artificial intelligence has enabled neural network programs to estimate age automatically.[3,9]

Age estimation is the process of determining a person's chronological age for medico-legal purposes, especially when a person's legal identity is at issue. Estimating a person's age is usually based on assessments of radiographs of the carpal bones in the hands, the jawbone, and the teeth. Therefore, it requires the consideration and judgement of radiographic experts. Age estimation through radiographic assessment requires standardized tools and high accuracy. It is necessary to develop an artificial intelligence system that addresses the subjectivity inherent to traditional methods commonly used by experts.[12]

Radiography is one area where artificial intelligence is applied. The evaluation parameters for the panoramic image are entered into the system, which learns and processes them to produce the desired output: an age estimate.[13] Parameters analyzed from panoramic radiographs include detection of prior treatment, such as root canal treatment; reconstruction from panoramic radiographs in poorly positioned patients; detection and classification of individual teeth; diagnosis of osteoporosis and jaw tumors; and segmentation of the dental region. Deep learning techniques applied to panoramic radiographs are one method for age estimation using radiographic scoring.[13]

Vila-Blanco et al[13] conducted a study using panoramic photographs analyzed with AI to estimate age. The 2289 panoramic photographs used were from the School of Medicine and Dentistry at the Universidade de Santiago de Compostela (Spain). Age prediction was performed using Convolutional Neural Networks (CNNs), which had demonstrated a strong ability to learn from medical images. This research used two network architectures to estimate age from panoramic images, Dental Age Net (DANet) and Dental Age and Sex Net (DASNet). DANet consists of one convolutional path and layers that learn features from panoramic images at different scales, producing an age estimate as output. The DASNet method is a method that adds a layer (second path) to estimate sex. This means that gender is considered to contribute to the accuracy of estimating age. Based on the results of this study, DASNet provides more accurate results than DANet. From this study, it can be concluded that DASNet can be used to estimate chronological age automatically and accurately, especially in young samples and at the dentition stage.[13]

De Back et al [14] did a study using Bayesian Convolutional Neural Networks (Bayesian CNN) on panoramic radiographs. The method was to formulate age estimation as a regression task and design a CNN using the Inception V3 architecture. The Inception V3 architecture was used for feature extraction, followed by two fully connected layers with 1024 and 512 neurons after global average pooling. In this study, the Bayesian CNN method can automatically estimate age from panoramic radiographs, but it does not guarantee the desired level of accuracy for daily use.

Research by Koch et al[15] developed a custom convolutional neural network (CNN) for

forensic age estimation based on orthopantomograms (OPGs) in individuals aged 1–25 years using a standardized methodology. All OPGs were normalized to 256 × 256 pixels and augmented to improve model generalization. The CNN architecture consisted of four convolutional blocks with approximately 69 million parameters, producing continuous age estimates via regression. The model was trained for 1000 epochs and evaluated against several transfer learning models (VGG-16, Inception-V3, DenseNet-201, ResNet-50, and EfficientNet-B4). The results show a MAE of 0.93±0.81 years, with 63% of estimates <1 year and 95% <2.5 years; the highest accuracy was observed for ages 1–8 years, and accuracy decreased with increasing age. Statistical analysis showed no significant difference in accuracy based on gender, except in the 6–11 age group. Compared to the transfer learning approach, the custom CNN showed superior performance and produced age estimates comparable to those of AGFAD forensic experts. Grad-CAM visualization indicates the simultaneous utilization of dental and non-dental features, although accuracy decreases in OPGs with low image quality or extreme dental conditions. This study confirms that a custom CNN is a robust, efficient, and applicable approach for forensic age estimation without requiring tooth segmentation.[15]

Štern et al[16] conducted a study using a Deep Convolutional Neural Network (DCNN) to estimate chronological age from MRI data. The DCNN architecture consists of blocks for extracting similar features, each containing convolution (conv) and pooling (pool). There is a fusion part, which is performed separately on the anatomical side. It gives the final representation of the extracted features. The age estimation is obtained by combining the extracted features from all three positions with a fully connected layer. From the results of their research, age estimation using the DCNN method through MRI images was very good. The average absolute error in predicting chronological age was 1.01 ± 0.74 years.[16]

Sex Determination

Sex determination is one of the most essential parameters for identification, especially in mass disasters, accidents, and solving medical problems, mainly in violence.[17] Skeletal bone is one of the strongest bones in the human body. It is the reason for using it as a parameter to determine sex.[12,17] Human teeth are one of the parameters used to determine sex in living people and cadavers.[12,18]

Sex determination using AI has begun to develop. Research by Patil et al[17] used the mandible as a parameter for artificial intelligence systems to determine sex. This study used an artificial neural network (ANN), which was increasingly being used in forensic odontology. Kozan et al[17,19] introduced this method and have used it to predict age and sex from skeletal bone parameters.

Several parameters were used to evaluate the ANN engine in the study by Patil et al[17] based on previous research. The parameters were: bigonial width (BiGW), bicondylar width (BiCW), condylar height (CoH), maximum ramus width (MRB), coronoid height (CorH), bimental width (BiMW), and gonial angle (GoA). BiGW is the distance between the two bigonial points. BiCW is the distance from the most lateral point of the two condyles. CoH is the distance from the highest line drawn perpendicularly from the uppermost point of the condyle to the horizontal line of maximum ramus width. MRB is measured from the diameter of the ramus in the anteroposterior direction. CorH is the distance from a line drawn perpendicular to the coronoid to the horizontal line of maximum ramus width. BiMW is the distance between the two mental foramina. GoA is measured by tracing a line from the lower edge of the lower jaw to the tangential of the distal edge of the ramus.[20] Patil et al's research uses a feed-forward neural network with input, hidden, and output layers. Two standard methods of sex determination, regression and discriminant analysis, were used to analyze the results. The accuracy of sex determination using ANN-based discriminant analysis is 69.1%, with 66.9% of males and 79% of females correctly identified. The accuracy of sex determination using ANN-based regression was 69.9%, with 72.2% of males and 67.4% of females correctly identified.[17]

Bitemark Analysis

Bite marks are one of the few pieces of evidence that can be found after a crime. However, this evidence can sometimes be controversial and require further investigation. Artificial intelligence bite mark analysis works by matching certain features of the recorded and analyzed bite to a model. In other words, bite mark data recorded as antemortem, stored in a database, and then matched with postmortem data by AI-based algorithms can be used to support identification.[9]

Research using AI to analyze bite marks was conducted on a Thai population in 2011.[21] The AI bite analysis was performed by taking bite data on dental wax in the following positions: chin up sitting, chin up, prone, supine, forward sitting, forward standing, chin down sitting, chin down standing, right sleeping, and left sleeping. The bites taken shall include all teeth in the sample. The bites taken must consist of all teeth in the sample. All bite samples are then photographed and fed into the artificial intelligence system. All bite samples are then subjected to a selection of specific features for the AI system to learn.[21]

The type of AI used to analyze bite marks is an Artificial Neural Network (ANN). The architecture used is a feed-forward neural network with 34 input points and 40 hidden neurons. The outcome was good. The accuracy of bite mark analysis using the method is 78-86% with an average of 82%. Bite-mark analysis using artificial intelligence has great potential in forensic science [21]

Facial Reconstruction

Humans have already used physical characteristics, such as the face and voice, to recognize each other. With the development of technology, biometric science has become one of the methods for identifying people based on biological characteristics.[22] Every person has characteristics that make them different from other people, so technology can distinguish and recognize these characteristics so that biometric technology can be used to confirm or establish a person's identity based on who they are.[22]

The 3D face reconstruction is a technique for improving the shape of face geometry from 2D data. This technique remains a challenge for researchers, especially in vision and graphics. Many approaches have been taken to overcome the problem. Jackson et al. researched face reconstruction using artificial intelligence, namely Convolutional Neural Network (CNN). They have done this by converting images from pixelated to three-dimensional (3D) coordinates. In this study, they used only one image as a source to reconstruct from 2D to 3D The images used have no boundaries, so images with different poses, expressions, and occlusions are obtained. CNNs are believed to be capable of being trained to judge from pixel-level features to higher-level values using only a single image as input. Facial reconstruction using a CNN shows good performance. CNN can convert 2D images into 3D in terms of facial posture and can track facial expressions and occlusion.[23]

Lip Print (Cheiloscopy Analysis)

Human identification using metric methods can be performed using various sources, such as fingerprints, DNA samples, and retinal scans. In forensic dentistry, lip prints are one of the parameters that can be used for metric measurement. [24] The technique to identify individuals through lip prints is called cheiloscopy.[24,25] Analyses of lip prints can include the shapes of lines, fissures, and lip wrinkles, as well as the presence of dental scars.[26,27]

Lips have a geometric shape that can be used to characterize individuals. Lip print analysis using AI measures the geometric shape of the lips using a probabilistic neural network.[9] The human lip print identification system begins with preprocessing, followed by pattern extraction, training, testing, and accuracy calculation.[24,26] Lip print analysis using artificial intelligence requires a dataset. After reviewing the study results, face datasets are used for learning and analysis due to the limited high-resolution lip-specific datasets and the ridge pattern on the lips.[28]

Lip print analysis is performed by analyzing facial landmarks. Landmarks are keywords for specific facial structures, such as the eyes, nose, mouth, and chin. For lip print analysis, the mouth

region is used as the region. In the human face, there are 68 coordinate pairs (x, y) that map the components of the face. The mouth-specific coordinates range from point 49 to 68. Therefore, the lip analysis method is usually followed by analysing the face, because the ordinate point is at the end of the face.[28]

Farrukh and van der Haar conducted research in 2020 to identify lip prints using machine learning and deep learning. The face landmark detection algorithm from the Dlib library is used to detect objects. The machine learning classifiers that they use are Support Vector Machine (SVM) and K-Nearest Neighbours (K-NN). Machine learning methods can result in fewer features being extracted. These methods yielded analyzed results with accuracies of 95.45% and 94.31%. The deep learning method used is a Convolutional Neural Network Classifier (CNN).[29] The CNN types used were the VGG16 and VGG19 architectures. They use this type because it is a good comparison architecture for a specific task. Deep learning can play a role in forming a biometric system to identify lip prints. The accuracy of this method was 91.53% and 93.22%. They concluded that although lip-print analysis is still in its infancy, deep learning for identification can deliver promising results like this.[28]

Zhou's research analyzed lip prints using a convolutional neural network, which has the advantage of directly examining the original lip print image and simplifying image processing. The accuracy of this technique is 99.06% for human identification.[29] Sandhya et al. conducted a study using K-Nearest Neighbours, Support Vector Machine, Artificial Neural Network, and Ensemble Classifier. Of these four classifier types, the Ensemble Classifier achieves better accuracy when features are extracted to identify individuals.[24]

Lip print analysis using AI is also used to predict gender. Machine learning is used to predict gender from specific lip features. The steps in analyzing lip prints to predict gender are data input, segmentation, preprocessing, feature extraction, and finally classification. Sabelli et al[27] used five classifiers to predict gender based on lip print patterns: K-Nearest Neighbours (K-NN), Multilayer Perceptron (MLP), Naïve Bayes (NB), Support Vector Machine (SVM), and Logistic Regression (LR). The classifier used, K-Nearest Neighbours (K-NN), gives good results where all models show accuracy in determining gender based on the pattern of lip prints.

Conclusion

Advances in science and technology have significantly influenced forensic odontology, particularly through the integration of artificial intelligence (AI). This AI has enhanced human identification by supporting key forensic tasks such as age estimation, sex determination, and stature analysis. Compared with conventional approaches, AI-based methods reduce subjectivity and improve analytical consistency. Machine learning techniques, including Support Vector Machines, Logistic Regression, K-Nearest Neighbours, and Naïve Bayes, as well as deep learning models such as artificial neural networks and convolutional neural networks, have demonstrated substantial potential in forensic dental applications. The growing adoption of these methods highlights AI as a valuable tool for improving the accuracy, efficiency, and objectivity of forensic dental identification.

Conflict of Interest

The authors affirm no conflict of interest in this study.

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