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Application of Artificial Intelligence in Forensic Medicine: Progress, Challenges and Future Prospects

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Abstract

With the rapid development of science and technology, artificial intelligence (AI) has become an important force to promote innovation in all walks of life. In the field of forensic medicine, the application of AI technology is gradually changing the traditional working mode, providing new tools and methods for judicial investigation, evidence collection, case analysis and other links. This paper reviews several key application fields of AI technology in forensic medicine, including face recognition, individual recognition, DNA analysis, time of death inference, damage and cause of death identification, and poison analysis, and discusses how these technologies can improve the accuracy, efficiency, and scientificity of forensic work. However, although AI has broad application prospects in forensic medicine, it also faces a series of challenges, such as algorithm selection and model generalization, representativeness and scale of data sets, selection and optimization of feature vectors, diversification and standardization of analysis platforms, and ethical and legal issues. In order to overcome these challenges and ensure the effective application of AI technology in forensic medicine, future research needs to focus on the adaptive learning of algorithms, the establishment of data sharing platforms, the development of feature selection tools, the formulation of industry standards, and the updating of ethical guidelines and legal systems. This paper aims to provide a comprehensive perspective to show the current application status, challenges and future development direction of AI technology in forensic medicine. Through in-depth analysis of these key issues, we hope to provide valuable information and inspiration for forensic professionals, researchers and policy makers, and jointly promote the healthy development of AI technology in forensic medicine.

Keywords

Forensic medicine; Artificial intelligence; Machine learning; Deep learning.

1. INTRODUCTION

The intersection of artificial intelligence (AI) and forensic science has opened a new frontier in the quest for truth and justice within the legal system. As AI technologies continue to evolve, they are increasingly being integrated into various aspects of forensic science, offering innovative solutions to age-old challenges. This integration is transforming the way evidence is analyzed, individuals are identified, and cases are resolved, leading to a more precise, efficient, and scientific approach to forensic investigations.

AI's application in forensic science spans a wide range of areas, each with its unique set of opportunities and challenges. In facial recognition, AI algorithms are pushing the boundaries of

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what is possible, aiding in the identification of individuals even when faced with significant changes in appearance over time or when dealing with large volumes of data from surveillance footage. The use of AI in DNA analysis, particularly with the advent of DNA methylation clocks, has revolutionized the way biological age and identity are determined, providing investigators with a powerful new tool for solving cases.

Moreover, AI's role in estimating the time of death through the analysis of postmortem microbiome changes is another significant development. This capability allows for a more accurate reconstruction of the timeline of events surrounding a death, which is crucial for solving criminal cases. In addition, AI's assistance in injury and cause of death determination, as well as toxicological analysis, is streamlining the process and enhancing the accuracy of these critical forensic tasks.

Despite the immense potential of AI in forensic science, the path forward is not without obstacles. Challenges such as algorithm selection, model generalization, dataset representativeness, feature vector optimization, and the need for analysis platform standardization must be addressed to ensure the reliable and ethical application of AI in this field. Furthermore, the ethical and legal implications of AI's role in forensic science must be carefully considered to maintain public trust and uphold legal standards.

This paper aims to provide a comprehensive overview of the current state of AI in forensic science, highlighting its applications, exploring the challenges faced, and discussing the future prospects of this dynamic field. By examining the latest research and developments, we hope to shed light on how AI can be harnessed to its full potential in forensic science while navigating the complex landscape of ethical and legal considerations.

2. APPLICATION OF ARTIFICIAL INTELLIGENCE TECHNOLOGY IN FORENSIC MEDICINE

2.1. Face recognition and individual recognition

The application of artificial intelligence technology in forensic face recognition is a rapidly developing field, which provides new tools and methods for judicial investigation and evidence presentation. According to bate et al.'s research, "super recognizers" refers to those individuals who are at the top of the normal population in terms of face recognition ability. They show the ability to recognize strangers who have not been seen for many years and whose appearance has changed significantly, recognize non famous actors in cross TV dramas and advertisements, and need self-regulation in social behavior to avoid frightening others [1]. This shows that AI has the potential to assist or enhance the ability of these extraordinary individuals in face recognition, especially in forensic face recognition research.

In forensic medicine, face recognition technology is mainly used in investigation and intelligence collection, as well as providing evidence in court. However, its reliability in court is still limited by insufficient method standardization and empirical validation, especially when using automated systems for image comparison and matching score generation [2]. In order to improve the reliability of forensic face recognition, more empirical research based on appropriate forensic data (such as surveillance videos and identity documents) is needed to make it an acceptable and reliable evidence method in court.

In the forensic framework, the application of face recognition can be divided into three main steps: investigation, intelligence and evaluation. In the investigation and intelligence stage, the automatic system can help to compare facial images with images in the database, generate a list of potential suspects, or compare with reference photos of specific individuals, providing effective clues for investigators [2]. At the evaluation stage, forensic experts need to interpret the results of facial image comparison in order to present them as evidence in court. At present,

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there is no standardized method to evaluate evidence derived from automated systems, which limits their use in court.

To solve these problems, a methodological workflow of score based likelihood ratio (SLR) calculation model based on Bayesian framework is proposed [2]. This method involves the evaluation of the discrimination ability and calibration status of the model, and quantifies and visualizes the performance characteristics of the model through the main indicators (such as equal error rate, EER, and cost of log likelihood ratio) and graphical representations (such as Tippett plot, detection error trade off plot, and empirical cross entropy plot) [2].

In general, the application of AI technology in forensic face recognition has great potential, but further research and standardization are still needed to ensure its reliability and effectiveness in court. Future work may include the development and validation of models, as well as the possibility of providing a preliminary assessment at the investigation stage, which will help investigators better understand the weights of preliminary results and guide subsequent investigations [2].

2.2. Age identification

By combining DNA methylation detection technology and AI algorithm, researchers can more accurately infer the biological age of individuals, which is of great significance for judicial expertise and criminal investigation.

First, DNA methylation is an epigenetic modification, and its level changes with the age of individuals. Studies have shown that the methylation status of thousands of CpG sites in the human genome changes with age. This finding provides the possibility of using DNA methylation to predict individual age [3]. Using a mathematical algorithm to calculate a group of CpG sites (called "clock CpG" sites), we can estimate the age of cells, tissues or organs. This estimated age is called epigenetic age or DNA methylation age.

In practical applications, researchers have developed multiple epigenetic clocks, such as Horvath epigenetic clock and Weidner epigenetic clock, which can predict the age of individuals based on specific CpG loci [3]. The establishment of these clocks provides a new tool for age inference in forensic medicine.

AI technology plays an important role in this process. Through machine learning models, such as support vector regression (SVR) and artificial neural network (ANN), researchers can conduct more in-depth analysis of DNA methylation data, thereby improving the accuracy of age inference [4]. For example, by combining a variety of statistical modeling methods, researchers can build more accurate age inference models, which can take into account different tissue-specific methylation sites, as well as other factors that may affect methylation levels, such as gender, health status and lifestyle.

In addition, AI technology also helps to solve some limitations of DNA methylation detection technology. For example, the existing technology may require a high amount of DNA input and may not be suitable for the detection of trace samples. AI algorithm can help improve the amount of information obtained from a small number of DNA samples, thus making age inference more widely used in forensic medicine.

2.3. DNA analysis

The application of artificial intelligence technology in DNA analysis in forensic medicine is increasingly becoming a key tool for case detection. With advanced polymerase chain reaction (PCR) technology, forensic scientists can extract DNA from micro samples, and use AI technology to improve the accuracy and efficiency of analysis. "In 1983, Kary Mullis proposed the PCR process, which can amplify specific DNA regions and provide a revolutionary tool for DNA analysis in forensic medicine" [5]. In addition, AI also plays an important role in forensic

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DNA phenotype prediction (FDP), which can predict the appearance characteristics, biogeographic ancestors and ages of unknown criminals from the DNA samples at the crime scene. "FDP includes predicting the appearance characteristics, biogeographic ancestors and ages of individuals from the DNA samples at the crime scene to provide investigation clues and help find unknown criminals that cannot be identified by forensic STR typing" [6]. In terms of age estimation, AI provides a new age prediction method for forensic medicine by analyzing methylation patterns in DNA samples, "DNA methylation analysis has been proved to have sufficient accuracy in forensic medicine, providing a practical solution for age estimation" [6]. The application of these technologies not only improves the scientificity and accuracy of forensic medicine, but also provides a new perspective and possibility for solving complex forensic problems.

2.4. Time of death inference

In forensic medicine, the estimation of the time of death is a crucial link, which can help determine the time line of the case, thus playing a key role in the investigation and settlement of the case. In recent years, the application of artificial intelligence (AI) technology has brought a new perspective and possibility to infer the time of death in forensic medicine. The following is a review of the application of AI technology in forensic time of death inference.

First, AI technology, especially machine learning and deep learning, shows great potential in analyzing a large number of datasets. These technologies can process and analyze complex data collected in forensic research, such as changes in microbial communities. For example, Mishra et al pointed out in their study that AI plays an important role in analyzing the postmortem microbial community and the microbial community during the decay of cadavers, and the changes of these microbial communities can provide information related to the time of death [7].

Secondly, AI technology has also shown its effectiveness in processing and interpreting microbial data related to postmortem interval (PMI). Through machine learning algorithm, the changes of microbial community after death can be modeled and predicted, thus helping forensic experts to more accurately infer the time of death. For example, the study of tuomisto et al showed that PMI can be effectively estimated by analyzing the changes of intestinal microbial community[8].

In addition, AI technology can also assist in inferring the time of death by analyzing other biomarkers in forensic medicine. In their review, dawidowska et al explored the application of metabolomics in forensic medicine, especially for forensic toxicology and time to death estimation [9]. Metabolomics can provide important information about physiological and pathological changes before and after death by analyzing metabolite changes in biological samples. Combined with AI technology, the data of these metabolites can be analyzed and interpreted more effectively to support the inference of the time of death.

2.5. Identification of injury and death causes

The application of artificial intelligence (AI) technology in forensic medicine is gradually improving the accuracy and efficiency of injury identification and cause of death inference. With advanced imaging technologies such as postmortem computed tomography (PMCT) and postmortem computed tomography angiography (pmcta), combined with AI algorithm, forensic scientists can more accurately analyze injuries, such as soft tissue and vascular structure injuries, and then infer the cause of death. Especially in cases of sudden cardiac death, AI is helpful to identify signs of coronary artery stenosis and other cardiac events. In addition, AI also plays an important role in disaster victim identification (DVI), which can quickly analyze body size data and assist in identity confirmation. Remote consultation and information sharing are also enhanced by AI technologies, such as virtual dissection through digital imaging and

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communication medicine (DICOM) format and proprietary software systems. These advances indicate that AI has a broad prospect of practical application in the field of forensic medicine, and it is expected to further realize standardization and automation in the future, so as to improve the consistency and accuracy of forensic analysis [10].

2.6. Toxicological analysis

Wendt et al took tramadol, an opioid analgesic, as the research object, and used a supervised machine learning classification algorithm to automatically classify CYP2D6 metabolic phenotypes by identifying single nucleotide polymorphisms (SNPs) at the CYP2D6 locus in blood samples collected from Finnish autopsy. This study provides new help for the investigation of causes and modes of death in forensic medicine [11].

3. CHALLENGES AND FUTURE PROSPECTS

Although the application of artificial intelligence in forensic medicine has great potential, it also faces a series of challenges.

3.1. Algorithm selection and model generalization

The problem of algorithm selection and model generalization requires us to carefully select algorithms and ensure that they can maintain consistent accuracy and reliability in different types of cases and samples. This requires that the algorithm not only have a high degree of adaptability, but also be able to continuously update and iterate with the development of forensic knowledge. For this reason, future research needs to focus on developing adaptive learning algorithms, and jointly promote the innovation and development of algorithms through interdisciplinary cooperation, such as experts in computer science, statistics and other fields.

3.2. Representativeness and size of the dataset

The representativeness and scale of datasets are also key factors that restrict the application of AI in forensic medicine. Because the collection of forensic data is limited by privacy and ethics, it is difficult to obtain large-scale and diverse datasets. In order to solve this problem, the future work needs to establish a cross institutional data sharing platform, adopt advanced privacy protection technologies, such as differential privacy, and data enhancement technologies, such as synthetic data generation, to expand and enrich the data set [12].

3.3. Selection and optimization of eigenvectors

The selection and optimization of feature vectors is also an important aspect of the application of artificial intelligence in forensic medicine. Effective feature selection and engineering can significantly improve the performance of the model. Future research needs to develop automated feature selection tools, combine the knowledge of forensic medicine, biology, chemistry and other fields, and jointly optimize the design of feature vectors.

3.4. Diversification and standardization of analysis platform

The diversification and standardization of analysis platforms are equally important. Due to the lack of unified standards and protocols, there are difficulties in compatibility and collaboration between different analysis platforms. Future work needs to formulate unified industry standards, adopt modular design, and develop intuitive and easy-to-use user interfaces to promote compatibility and collaboration between different platforms, while reducing the technical threshold.

3.5. Ethical and legal issues of artificial intelligence in forensic medicine

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Ethical and legal issues are important aspects in the application of AI in forensic medicine. With the in-depth application of artificial intelligence technology, how to protect personal privacy, clarify the responsibility and adapt to the existing legal system is a challenge we must face. Future work needs to formulate the ethical guidelines of artificial intelligence in forensic medicine, establish a clear responsibility attribution mechanism, and promote the renewal of the legal system to adapt to the development of artificial intelligence.

3.6. Standardization of AI technology in forensic medicine

The standardization and standardization of technology is the key to ensure the reliability of the application of artificial intelligence in forensic medicine. Future work needs to establish standardized AI application process, implement quality certification system, and carry out AI technology training for forensic professionals to improve application ability and ensure the reliability of analysis results [13].

4. CONCLUSION

This paper discusses the diverse applications of artificial intelligence (AI) technology in forensic medicine and its significant impact on improving the efficiency and accuracy of judicial investigation. In face recognition and individual recognition, AI technology provides a new tool for forensic medicine by enhancing the ability of "super recognizers", especially when dealing with forensic data such as surveillance videos and identity documents. In the field of DNA analysis, AI, combined with DNA methylation technology and advanced polymerase chain reaction (PCR) technology, provides a new solution for inferring individual biological age and extracting DNA from micro samples. In addition, AI technology provides a more accurate inference tool for forensic experts by analyzing the changes of postmortem microbial communities in the time of death inference. In the identification of injury and death causes, AI combined with advanced imaging technologies, such as postmortem computed tomography (PMCT) and postmortem computed tomography angiography (pmcta), improved the accuracy of injury analysis. In poison analysis, the application of AI improves the efficiency of detecting and identifying poisons from complex samples.

Although AI has a promising application in forensic medicine, there are also some challenges. The adaptability and generalization ability of the algorithm need to be further enhanced to ensure that they can maintain consistent accuracy and reliability in different types of cases and samples. The representativeness and scale of datasets limit the potential of AI technology, so it is necessary to establish a cross institutional data sharing platform, and use privacy protection technology and data enhancement technology to expand datasets. The selection and optimization of feature vectors is the key to improve the performance of the model. Future research needs to develop automated feature selection tools and optimize the design of feature vectors combined with multi domain knowledge. The diversification and standardization of the analysis platform need to be solved by formulating unified industry standards and adopting modular design. Ethical and legal issues can not be ignored in the application of AI in forensic medicine. It is necessary to formulate ethical guidelines for AI in forensic medicine, establish a clear responsibility attribution mechanism, and promote the renewal of the legal system.

In conclusion, the application of AI technology in forensic medicine not only shows its great potential, but also reveals the direction of future development. Through continuous research and standardization, AI technology is expected to play a greater role in the field of forensic medicine in the future, providing stronger support for judicial justice and case resolution. This requires the joint efforts of forensic professionals, researchers, and policy makers to ensure the reliability and effectiveness of AI technology, while addressing the ethical and legal issues that accompany its application.

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