Review Article

Digital detectives: Exploring the integration of artificial intelligence in Indian forensic medicine

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ABSTRACT

Forensic Medicine is the application of medical knowledge for law and administration of justice, which involves conducting the medico-legal post-mortem examination, estimation of the age of the individual, victim-accused examination and the study of poisons in all aspects. Many times, minute details of the examination are often missed by the naked eye, especially if the expert is inexperienced or if the autopsy is conducted at night time leading to high numbers of negative or obscure autopsies. As Artificial Intelligence is booming the smoothening of the work in all specialities like finance, administration, transportation, health care and the medical field, its applicability can smoothen the work of forensic medicine experts. It can offer the result more accurately, efficiently, precisely and within no time at low cost as compared to contemporary services. This review explores the applications, benefits, challenges, and prospects of AI in forensic medicine within the Indian context. By examining recent advancements and case studies, this paper aims to offer a comprehensive understanding of AI's impact on forensic practices in India.

1. Introduction

Forensic medicine involves applying medical knowledge to assist in the administration of law and justice. It also encompasses toxicology, which is the study of poisons in all aspects, including their extraction, identification, signs & symptoms, and their management. The main duties of forensic experts include conducting medicolegal postmortem examinations, estimating age, examining victims and accused, and performing other medicolegal tasks. A medicolegal postmortem aims to determine the cause of death, manner of death, mode of death, and time since death, identifying the deceased, and distinguishing whether injuries are antemortem or postmortem. In the case of fetal autopsies, a key challenge is to ascertain whether the fetus was born alive or stillborn. Some crucial parameters can be assessed visually, but determining the exact time of death, color changes in injuries, and crime scene examination especially during night time autopsies, often presents difficulties for forensic experts.[1–4]

The history of artificial intelligence (AI) reflects the contributions of many pioneers and evolving technologies. The formal concept of AI, established in the mid-20th century, goes much to Alan Turing's groundbreaking work, which proposed the idea of machines simulating human intelligence.[5,6] AI has moved from theoretical research to become integral in various fields, including finance, transportation, healthcare, and medicine. In medicine, AI

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has notably improved diagnostic accuracy, personalized treatment plans, and streamlined administrative processes.[1]

In forensic medicine, AI offers transformative potential. The integration of AI technologies in this field promises to enhance accuracy, efficiency, and investigative capabilities. Advanced algorithms and machine learning enable AI to analyze complex forensic data, such as DNA profiles and digital evidence, with exceptional speed and precision. This capability significantly aids forensic experts by reducing the time needed for evidence analysis and enhancing the accuracy of crime scene reconstructions and autopsies. Forensic experts in India will benefit from AI through improved diagnostic tools, predictive analytics for identifying criminal patterns, and advanced data management systems that support more effective case resolutions. Thus, AI is set to revolutionize forensic medicine in India by providing powerful tools that enhance the efficacy and accuracy of forensic work, ultimately contributing to more effective justice delivery and public safety.[5–9]

This review explores the applications, benefits, challenges, and future prospects of AI in forensic medicine within the Indian context. By examining recent advancements and case studies, this paper aims to offer a comprehensive understanding of AI's impact on forensic practices in India.

2. Uses of AI in Forensic Medicine

1. **Identification** – A medicolegal post-mortem examination is crucial, particularly in cases involving unknown, unclaimed, mutilated, or significantly decomposed bodies, or in situations where bodies are recovered from mass disasters such as tsunamis, floods, earthquakes, landslides, bomb explosions, or transportation accidents. Traditionally, methods such as anthropology, facial descriptions, tattoos, scars, and other body marks were employed for identification. However, advancements in technology have introduced DNA and fingerprint analysis as valuable tools for identifying the deceased. With the rise of artificial intelligence (AI) and machine technology, the identification process has become more efficient. AI systems can analyse and store data from various parameters, including facial features, retinal patterns, and fingerprints, electronically. By comparing the pre-existing data stored in these systems, AI technology facilitates quicker, more accurate and cost-effective identification. To enhance this process, fingerprints are routinely collected and stored in various settings, such as schools, medical colleges, and corporate offices. Expanding this practice to include large-scale data collection, including from rural populations, could significantly revolutionise identification procedures, improving both accuracy

and efficiency.[1,10,11]

2. **Biometric** is the biological data of the individual such as iris pattern, facial features, gait pattern, DNA pattern, palm print and voice pattern. The application of biometrics for identification is known as biometry. If the data is stored in the system, the identification can be achieved in no time using AI.[1,12]

3. **Stains** on the clothes as well as on the body are often missed on naked eye examination which gives an important clue of the crime or the identification of the individual. A salivary stain from the angle of the mouth is the diagnostic and most important feature of antemortem hanging, the presence of a seminal stain is a definite clue of sexual intercourse, the presence of blood stains on the weapon, and if this is similar to that of victim confirms the weapon of offence. The collection of evidence is an experience-based work, so many times it is often missed by the naked eye, especially in the case of an inexperienced expert. AI microscopy imaging technique can visualize sperm stains by deep convolution neural network technique more accurately than the conventional techniques.[1,13]

4. **Color changes** in the abrasion as well as bruise are the important factors determining the age of injury hence proving or disproving the testimony of the accused. Colour interpretation by mere naked eyes is a subjective, experienced and subject-biased job. Computer-aided colour detection techniques can analyse the colour more accurately from the wound. The machine is provided with various graph-related trauma time intervals and changes in the colour pattern of a wound. By comparing the available data, the machine can interpret the time interval of injury in no time and a very accurate manner.[1,5,14–17]

5. **Virtual autopsy** or virtopsy is a hot topic among debates in the conferences held by the subject specialists of forensic medicine. With the AI-driven virtual autopsy technique using CT scan and MRI, the machine will identify the pathological condition of the organ from the data already saved into the system. The machine will process the data and conclude the pathology of the organs, thus minimising the chances of negative or obscure autopsy. Even from the minute pathology, the definite cause of death will be framed and thus justice will be properly administered to the affected party.[1,18]

6. **Post-mortem interval** – Another crucial objective of medico-legal post-mortem examination is to find out the time since death, which is also a subjective phenomenon by using rigor mortis, algor mortis, post-mortem hypostasis, rate of decomposition of the body. Various studies have demonstrated the increasing or decreasing level of biomarkers like sodium, potassium, calcium, and LDH in various bodily fluids like

pericardial, vitreous humor and synovial fluid. With AI-driven machines, the time since death can be accurately measured from the biomarker data and their changes with respect to time after death.[5,19,20]

7. Photo spectrometer, chromatography, neutron activation analysis, and gas or liquid chromatography are the techniques employed for toxin analysis in laboratories. Though the techniques are advanced, the chances of human error in interpreting and collecting data cannot be curtailed. AI can help in this if the set of algorithms is provided to the machine, thus things can be done easily and time efficiently. If AI robots are employed for the collection, transportation and processing of toxicological samples, the more accurate results can be achieved in less time as compared to conventional techniques.[1,21]

8. **Forensic psychology** – AI can be used in the lie detection test and narco-analysis to give fast, accurate and nonbiased results; however, ethical issues should be kept in mind.

9. **Automated Crime Scene Analysis** – AI technologies, including computer vision and image recognition, are increasingly being used to analyze crime scene photographs. These systems can categorize and identify objects, track movements, and even reconstruct crime scenes. Computer vision algorithms can process high-resolution images from crime scenes to identify and analyze objects, detect bloodstains, and even reconstruct events. These technologies enhance the ability of forensic teams to understand and interpret crime scenes accurately.

10. **Digital Forensics and Evidence Analysis:** Digital forensics involves the recovery and analysis of electronic data, which is increasingly vital in modern investigations. AI algorithms, particularly those based on machine learning, play a pivotal role in processing and analyzing large volumes of data. Machine learning models can analyze digital evidence such as emails, social media interactions, and text messages. These models identify patterns and anomalies that may be indicative of criminal activity, often more efficiently than traditional methods.

11. Besides this usage in the context of forensic medicine, gender determination, age estimation, forensic odontology, ballistics, crime scene reconstruction, 3D facial reconstruction, and digital forensics can be done easily.[5,22–24] Apart from this AI can be helpful in other domains of medicine like disease diagnosis by using CT, MRI and PET scan, disease surveillance.

3. Benefits of AI in Forensic Medicine

1. **Enhanced Accuracy and Efficiency** – AI systems significantly increase the accuracy and efficiency of forensic processes. By automating repetitive tasks and analyzing complex datasets, AI reduces the likelihood of human error and speeds up investigations. AI's ability to process large amounts of data and identify subtle patterns enhances the accuracy of forensic analyses. This improvement is particularly evident in areas such as digital forensics and DNA profiling.

2. **Improved Investigative Capabilities** – AI tools offer advanced capabilities that enhance investigative processes. By providing detailed analyses and predictive insights, AI supports law enforcement in solving cases more effectively. AI's ability to reconstruct crime scenes and analyze evidence in detail has improved the overall investigative process, leading to more informed decisions and successful case resolutions.

3. **Cost-Effectiveness** – The use of AI in forensic medicine reduces operational costs by automating time-consuming tasks. This cost-effectiveness is achieved through the reduction of manual labor and the acceleration of data processing. AI integration leads to significant cost savings by minimizing the need for extensive manual analysis and enabling more efficient use of resources.

4. Challenges and Limitations

1. **Data Privacy and Security** - AI in forensic medicine raises significant concerns regarding data privacy and security. Ensuring the protection of sensitive information is crucial in maintaining public trust and compliance with legal standards. AI systems often require access to large volumes of personal and sensitive data, raising concerns about potential breaches and misuse.

2. **Ethical Considerations** - The ethical implications of AI in forensic medicine include the potential for algorithmic biases and the need for transparency in AI processes. Ensuring that AI systems are used responsibly and ethically is essential for maintaining fairness and justice. AI algorithms can inadvertently perpetuate biases present in training data, leading to unfair outcomes. Addressing these biases and ensuring equitable use of AI is crucial.

3. **Technical Limitations** - AI technology still faces technical limitations despite advancements. Issues such as the quality of training data and algorithmic inaccuracies can impact the effectiveness of AI systems. The performance of AI systems heavily depends on the quality of the data used for training. Inaccurate or incomplete data can lead to suboptimal results.

4. **Training of machine** – the AI machine requires a large amount of data feed for accurate interpretation. Data should be in large quantities and qualities. Many of the researchers nowadays are doing the research by

taking the sample size of 100 or 200 or even more, but this small data interpretation cannot be applied equally to the whole of the population. Therefore, research study should be conducted on the large number of populations accurately and then inputs should be made so as to calculate the exact desired parameters based on the large set of stored data into the machine.

5. **Infrastructure** – AI driven machines includes the high-performance computing infrastructure, large data storage system which are very expensive. Basic health facilities and emergency services are not always present at all location in the developing nation, Whether the poorer nations and developing nations like India will be able to afford this is a matter of grave concern.

6. **Human interaction and trust** – AI is a fully automated machine, which will lessen the interaction between the expert and the justice-seeking party if we talk about forensic medicine practice. So, keeping this in mind, whether the victim will be consoled or not is another important issue to be kept in mind.

7. **Cross-questioning** – An oral evidence is always kept superior to documented evidence because oral testimony can be cross-examined by the lawyer of the opposite party. So, whether the court or law will recognise AI-driven automatic tools for the opinion or the medicolegal implication is another question of concern.

5. Discussion

As technology continues to evolve at a rapid pace, it plays an increasingly significant role in enhancing human comfort, relaxation, and mental well-being. However, every technological process or machine presents both advantages and disadvantages, which are contingent upon their application and the degree of reliance placed upon them. No technology or machine offers an infinite array of benefits that can be enjoyed without exercising caution and restraint. Conversely, it is equally inaccurate to categorise any technology as solely disadvantageous without acknowledging its merits. The balance between advantages and disadvantages hinges on the frequency of use, dependency on the technology, and the regularity of updates and improvements. Artificial intelligence (AI), for instance, has emerged as a significant asset across various sectors, particularly within the healthcare system. In forensic medicine, AI can be particularly advantageous, as it aids forensic experts in identifying minute details that may be overlooked by the naked eye. This capability is instrumental in reducing the incidence of inconclusive or erroneous autopsies often termed obscured and negative autopsies. AI applications in forensic medicine include identifying deceased individuals, analysing biometric data, detecting stains, observing colour changes in injuries,

conducting virtual autopsies, calculating the time since death, and enhancing forensic psychology. Nonetheless, several critical considerations must be addressed when incorporating artificial intelligence into everyday forensic practice. These include data privacy and security, ethical implications, technical limitations, infrastructure readiness, machine training, the nature of human interaction, trust issues, and the capacity for effective cross-examination.

6. Future Prospects

The future of AI in forensic medicine in India looks promising, with ongoing research and technological advancements which is likely to address the current limitations. Continued innovation and collaboration between technology developers and forensic professionals will be the key to maximizing AI's potential. Future developments in AI are expected to enhance the capabilities of forensic medicine, leading to more accurate and efficient investigative processes.

7. Conclusion

AI promises a range of benefits for medical personnel especially forensic experts in the field of medicolegal autopsy, toxicological analysis, crime scene reconstruction and DNA profiling, however, it requires a huge amount of qualitative as well as quantitative data to be saved into the system for training of machines and hence to give more accurate results. So initially forensic experts have to do tremendous work in the research field so that the results can be applied globally universally. Continued research and development in this area hold the promise of further advancements and improvements in the forensic field. Another issue with AI is its legality in India and whether the court of law will consider the opinion derived from AI technology and whether will it be admissible in court or not is a matter of grave concern. However, the opinion can be used as a shred of corroborative evidence. Settling up a high-end infrastructure in forensic medicine will also be a big challenge for policymakers in developing countries like India. Trust in forensic experts and ethical issues should also be kept in mind in fully using AI technology in the field of forensic medicine in India.

AI is making significant inroads into forensic medicine in India, offering numerous benefits such as enhanced accuracy, improved investigative capabilities, and cost-effectiveness. However, addressing challenges related to data privacy, ethics, and technical limitations is crucial for the successful integration of AI into forensic practices. With ongoing advancements and research, AI is set to play a transformative role in the field of forensic medicine, improving both the efficiency and effectiveness of investigations. In conclusion, while the integration of artificial intelligence into forensic medicine holds great

promise, it is imperative to navigate these challenges thoughtfully to ensure the technology is employed responsibly and effectively.

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