Review of Contemporary Philosophy
ISSN: 1841-5261, e-ISSN: 2471-089X
Vol 23 (1), 2024
Pp 1432 - 1452

Forensic Toxicology in the Modern Era: Overcoming Challenges and Harnessing New Trends Via Utilization of Artificial Intelligence

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Abstract:

Background: The Fourth Industrial Revolution has ushered in transformative technological advancements, with Artificial Intelligence (AI) playing a pivotal role across industries. In forensic toxicology, AI offers unparalleled potential to enhance the accuracy and efficiency of biological sample analysis, criminal investigations, and medicolegal autopsies. Despite its promise, challenges such as ethical concerns, data privacy issues, and infrastructural requirements hinder widespread adoption.

Aim: This review explores the transformative role of AI in forensic medicine and toxicology, emphasizing its applications, potential benefits, and associated challenges. It aims to outline critical advancements required to harness AI's full potential in these fields.

Methods: A comprehensive literature review was conducted, examining existing and emerging applications of AI in forensic medicine and toxicology. The review focused on AI's role in data analysis, omics research, forensic autopsies, and toxicological assessments. Limitations, ethical concerns, and infrastructural needs were also evaluated.

Results: AI-driven technologies enhance forensic investigations by automating labor-intensive tasks, increasing diagnostic precision, and enabling predictive analyses. Applications include virtual autopsies, injury age estimation through omics data, and the identification of novel toxins.

However, limitations include reliance on high-quality datasets, ethical considerations, and significant investment in infrastructure and interdisciplinary collaboration.

Conclusion: AI is revolutionizing forensic toxicology and medicine, offering innovative solutions to longstanding challenges. While it enhances efficiency, precision, and reliability, its integration necessitates addressing ethical, technological, and operational barriers. Collaboration between stakeholders is essential to ensure AI complements human expertise, fostering trust and reliability in forensic practices.

Keywords: Artificial Intelligence, Forensic Toxicology, Medicolegal Autopsy, Omics Data, Ethical Challenges, Fourth Industrial Revolution, Biometric Identification

Received: 07 october 2024 **Revised:** 26 November 2024 **Accepted:** 18 December 2024

Introduction:

The Fourth Industrial Revolution is fundamentally altering various industries, with Artificial Intelligence (AI) serving as a crucial factor propelling digital transformation efforts. In recent years, there has been a notable increase in the utilization of AI across multiple sectors, including healthcare, where it has shown promise in identifying skin cancer, monitoring vital signs, and assisting physicians in improving diagnostic precision. In the field of toxicology, AI possesses significant potential for enhancing the examination of biological samples [3]. AI has the potential to transform procedures in forensic medicine and toxicology by empowering forensic medicine experts and toxicologists to do complex analytical tasks. This review analyzes the prospective impact of AI on various domains and delineates the essential breakthroughs necessary for AI to effectuate a transformational influence.

The Fourth Industrial Revolution is ushering in a transformative era marked by rapid advancements in technology, with Artificial Intelligence (AI) serving as a linchpin of digital innovation [1]. As industries adopt AI-driven solutions, their applications are extending beyond traditional technological boundaries to reshape practices across healthcare, forensics, and toxicology. AI's unique ability to process and analyze vast datasets, identify patterns, and deliver actionable insights has made it an indispensable tool in the modern era. This evolution underscores the necessity of integrating AI into specialized fields, including forensic medicine and toxicology, to address complex challenges and enhance operational efficiency. In healthcare, AI has already demonstrated its transformative capabilities. From detecting skin cancer through image recognition algorithms to monitoring vital signs with wearable devices and supporting diagnostic accuracy, AI is revolutionizing clinical care [2]. These successes highlight its potential to address intricate tasks that demand precision and speed. In toxicology, where the analysis of biological samples often involves multifaceted procedures and large volumes of data, AI could significantly streamline workflows. By automating labor-intensive tasks, such as the identification of toxins and interpreting toxicological profiles, AI could reduce errors and improve the reliability of results, fostering advancements in both clinical and forensic toxicology.

The integration of AI in forensic medicine and toxicology extends beyond data analysis. It has the potential to assist experts in predicting the effects of chemical exposures, identifying novel toxins, and providing probabilistic assessments of exposure-related outcomes. AI-driven platforms can enhance the interpretation of autopsy findings, simulate the impact of various substances on biological systems, and support legal proceedings by delivering evidence-based insights. Furthermore, AI algorithms can analyze patterns in historical toxicological data to predict future trends, contributing to public health initiatives and preventive measures. Despite these advantages, the implementation of AI in toxicology and forensic medicine is not without challenges. Issues such as data privacy, the need for standardization in AI algorithms, and the ethical implications of AI-driven decision-making must be carefully addressed. Moreover, the integration of AI requires substantial investment in infrastructure, training, and interdisciplinary collaboration to ensure that professionals can effectively utilize AI tools. These challenges necessitate a concerted effort from researchers, policymakers, and industry stakeholders to create robust frameworks for AI adoption. This review aims to explore the transformative potential of AI in the fields of forensic medicine and toxicology. By analyzing its current applications and examining the barriers to its widespread adoption, the review highlights the critical advancements needed for AI to achieve meaningful impact. With its ability to automate complex analytical processes and deliver precise, evidence-based insights, AI represents a paradigm shift in toxicology and forensic practices. However, realizing its full potential requires addressing technological, ethical, and operational challenges, ensuring that AI serves as a complement to human expertise rather than a replacement. Through this comprehensive exploration, the review underscores the significance of AI as a disruptive force in toxicology and forensic medicine. Its integration promises not only to enhance efficiency and accuracy but also to redefine the scope of these fields, paving the way for innovations that benefit both professionals and society at large.

Forensic Medicine and Toxicology:

Forensic medicine entails the utilization of medical knowledge within the domains of law enforcement, criminal investigations, and judicial processes. Toxicology is the scientific examination of the detrimental effects of chemicals on human health, primarily concentrating on the interactions between natural and manmade chemicals and the human body. Toxicology is subdivided into multiple subspecialties. Clinical toxicology investigates disorders induced by toxic agents, whereas medical toxicology concentrates on the management of poisoning. Occupational toxicology examines exposure to harmful chemicals in the workplace, while analytical toxicology focuses on the identification and quantification of toxins. Toxinology examines toxins generated by living organisms that threaten human health. Forensic toxicology utilizes these ideas within the legal and judicial system to examine and interpret evidence in criminal situations [5]. Toxicology includes a wide range of compounds, such as prescription and over-the-counter medications, alcohol, opioids, illegal drugs, and environmental pollutants. Forensic medicine and toxicology, as fundamental fields of forensic science, are crucial in numerous legal and investigative contexts. This encompasses crime scene examinations and courtroom processes, wherein forensic professionals utilize techniques such as DNA and fingerprint analysis, examination of blood and fluids, and the investigation of trace evidence including hair, fibers, and weapon residues. This article analyzes the revolutionary capacity of artificial intelligence (AI) in forensic medicine, highlighting its contribution to enhancing the precision and efficacy of forensic investigations.

Artificial Intelligence in Forensic Medicine and Toxicology:

AI denotes the creation of intelligent systems that can do tasks usually necessitating human intelligence. In forensic medicine, conventional techniques, such as manual autopsies, frequently encounter constraints, including dependence on skilled practitioners, the possibility of human error in observations, and subjective heterogeneity in expert assessments. The incorporation of modern technologies such as AI is essential for surmounting these constraints and attaining enhanced accuracy in medicolegal autopsies. In medicolegal autopsies, forensic specialists are responsible for determining identity, studying stains on clothing or the body, collecting biological specimens, and assessing injuries and pathological conditions. Artificial intelligence can improve these procedures by recognizing subtle fractures or injuries that may be missed during manual assessments and identifying inflamed regions resulting from toxins. Furthermore, AI algorithms may examine trace evidence such as blood, seminal stains, and fingerprints, enabling forensic specialists to obtain more precise and consistent results by juxtaposing findings with established datasets within AI systems. Additionally, AI can assist in weapon analysis and the determination of time since death, where accuracy is critical [6]. The identification of individuals, a crucial element of forensic medicine, has conventionally depended on methods such as anthropological studies, face descriptions, and DNA testing. The identification processes can be transformed by AI. AI systems can retain and assess biometric data, such as face characteristics, retinal patterns, and fingerprints, facilitating swift and precise identification verification. These systems are currently utilized extensively, for example, in attendance monitoring within educational and corporate environments [7,8]. This review utilizes comprehensive literature to delineate potential uses of AI in forensic medicine and toxicology. The integration of AI is set to revolutionize the discipline, equipping forensic specialists with instruments to improve precision, efficacy, and uniformity in their evaluations, while tackling obstacles in criminal inquiries and mass casualty incidents.

The utilization of biometric data for person identification has emerged as a crucial application in forensic medicine. Biometric criteria, such as fingerprints, iris patterns, facial features, gait patterns, DNA profiles, palm prints, and voice patterns, are employed to verify identity. This procedure, termed biometry, involves comparing a given biometric pattern, such as a fingerprint, with pre-stored data in a machine. This method is especially advantageous for large-scale applications but presents considerable obstacles with infrastructure and resources when executing biometric data collecting for vast populations [9]. Artificial intelligence can augment forensic methodologies in multiple capacities. External stains or alterations in bodily coloration, such as seminal fluid stains in sexual assault cases, are essential for criminal investigations. Conventional visual inspections frequently overlook nuanced indicators or are compromised by insufficient sample acquisition. AI-enhanced microscopy, utilizing deep convolutional neural networks, provides enhanced precision in identifying sperm stains, fingerprints, or blood splatter patterns. Likewise, AI-driven color detection methods can precisely assess alterations in bruise pigmentation to determine the time of the injury. By juxtaposing trauma data with wound color diagrams, these methods yield accurate interpretations of injury timelines [10,11].

AI has also changed forensic autopsies. Virtual autopsies utilizing machine learning examine CT or MRI scans to identify pathological disorders, diagnose fractures or tissue damage, and ascertain weapon types by correlating injury dimensions with established datasets. This approach enables precise sample collection from diseased locations, facilitating reliable diagnoses and determinations of causes of death [6]. A significant forensic application of AI is in determining the post-mortem interval (PMI). Biomarkers, including lactate dehydrogenase (LDH), blood pH, and electrolyte concentrations, exhibit predictable alterations over time post-mortem. Artificial intelligence may analyze these biomarkers through statistical models to ascertain the period since death with considerable precision [12,13]. In forensic toxicology, artificial intelligence mitigates obstacles in chemical analysis, such as human error and complexity. AI-driven algorithms optimize methodologies like chromatography and spectrometry, enhancing efficiency and precision. The use of robotics further automates activities like sample collecting and transport, hence boosting efficiency and dependability [14]. In addition to these uses, AI possesses transformative potential in other fields, such as disease diagnosis via imaging, pathogen surveillance for outbreak monitoring, and expediting autopsy reports by highlighting essential discoveries. In toxicology, AI aids in the analysis of biological samples for drugs and toxins and in the identification of drug usage patterns through sophisticated software analytics [6,15,16,17].

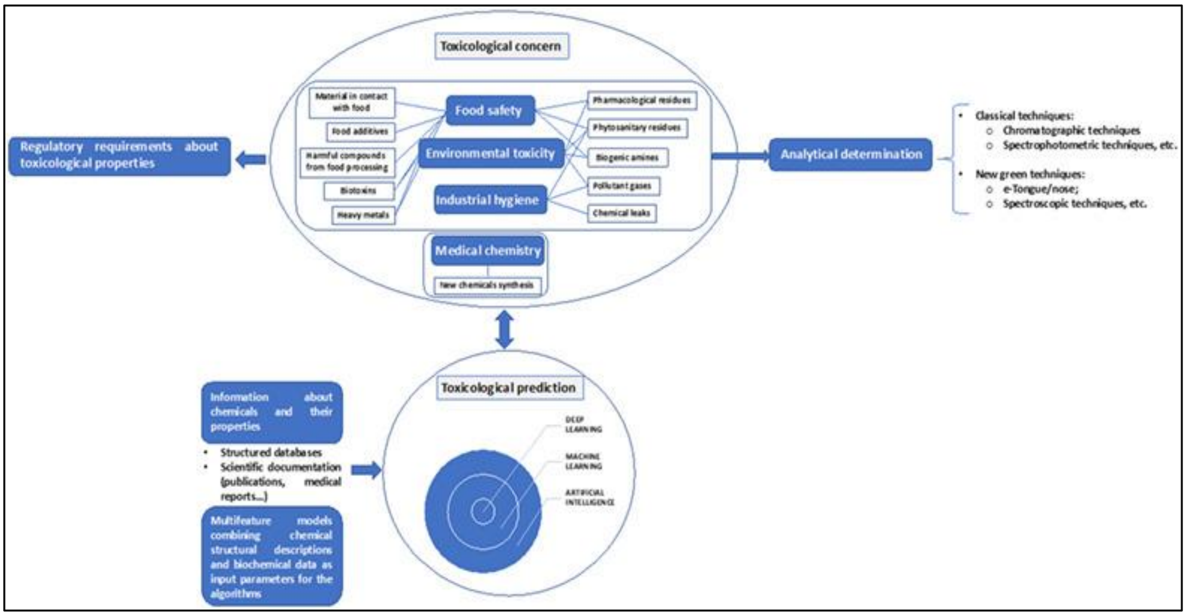

Figure 1: AI and Predication of Toxicity.

Omics Data Mining Using AI

The term omics includes several fields of biological sciences, including genomics, proteomics, metabolomics, and toxicogenomics. These technologies produce extensive scientific data with considerable potential for forensic applications, such as predicting postmortem intervals, detecting diseases, and assessing drug abuse and poisoning situations. The use of omics data into forensic science has increasingly emerged as a research priority across various forensic subdisciplines [18]. Genomics has been utilized to assess wound age via DNA microarray analysis of skeletal muscle specimens in injury patients [19]. The swift advancement of omics technologies, which produce data on gene expression, protein quantity, metabolite concentrations, and microbial interactions, has significantly propelled biological and medical research. When integrated with machine learning (ML) technologies, omics data can be utilized in forensic medicine to identify biomarkers and diagnose diseases with unparalleled precision [20]. The application of omics in forensic research involves utilizing mathematical modeling and data analysis to elucidate intricate biological processes. Genomics-based research has shown that time-dependent mRNA expression in contused muscle can ascertain the age of contusion injuries [21]. Future paths in forensic research will focus on multi-omics studies combined with AI algorithmic modeling. The concurrent examination of various omics datasets—namely genomes, transcriptomics, and metabolomics—via AI improves the holistic comprehension of intricate biological processes and disease mechanisms. This integrative approach facilitates the systematic examination of regulatory processes in forensic situations, leading to enhanced and dependable forensic procedures [22].

Limitations of AI in Forensic Medicine and Toxicology

AI systems necessitate comprehensive, high-caliber datasets for proficient training and precise analysis. In forensic medicine, this involves compiling extensive collections of annotated data, comprising photos and papers, supplemented with essential forensic findings and conclusions. Forensic professionals are essential in training these systems, as they must carefully label and annotate data to allow the machine to interpret results appropriately during postmortem exams. The initial phase requires significant time and effort, highlighting the necessity for collaboration between AI developers and forensic experts.

The integration of AI in forensic medicine presents substantial ethical dilemmas and regulatory issues. Although AI improves precision and operational efficacy, its use prompts apprehensions about the diminishment of human discernment, especially in critical domains like legal and medical decision-making. Ethical concerns emerge with data privacy, biases in algorithmic design, and accountability for AI-generated results. Regulatory regimes must adapt to reconcile innovation with ethical accountability. Establishing confidence in AI-generated forensic findings is a significant challenge. Forensic professionals must guarantee that stakeholders, including the judiciary, investigative agencies, and the public, regard AI-generated assessments as precise and trustworthy. This necessitates stringent validation of AI systems and a clear explanation of approaches. Forensic experts must integrate AI-generated insights with existing forensic methods to enhance stakeholder confidence. By mitigating these limits via collaborative training, stringent ethical monitoring, and transparent methods, the incorporation of AI into forensic medicine and toxicology might realize its full potential while preserving public and professional trust.

Integrating AI into forensic medicine necessitates a resilient infrastructure, comprising high-performance computing systems and substantial data storage capacities. Such configurations entail considerable expenses, prompting apprehensions over affordability, especially in economically disadvantaged countries. Establishing the requisite infrastructure in resource-constrained environments may be infeasible without significant investments and global assistance. Policymakers must evaluate the expenses relative to the possible benefits while accounting for the financial limitations of these locations. AI functions as an advanced instrument but cannot replace the intricate discernment and proficiency of human forensic experts. All datasets employed by AI systems necessitate significant human involvement, especially during the training process. Forensic specialists must invest considerable effort to provide precise, annotated data to AI systems, guaranteeing dependable interpretations. Moreover, these systems require frequent upgrades to align with the changing landscape of forensic methodologies and developing data patterns, emphasizing the essential necessity of human participation.

A significant obstacle in the integration of AI in forensic medicine is the absence of compatibility among diverse AI systems. Divergent systems frequently lack good communication, resulting in data silos and redundant efforts. This fragmentation diminishes the collaborative capacity of AI and requires the establishment of standards protocols to provide smooth integration across platforms. The acceptability of AI-generated conclusions in legal contexts is a critical issue in forensic medicine. In legal proceedings, forensic evidence generally necessitates spoken testimony from specialists. Thus, the acceptance of AI-generated insights as primary evidence remains ambiguous. Although these views may provide corroborative evidence, their acceptance relies on the judiciary's comprehension of AI's operations and constraints. The evolution of regulatory frameworks and expert evaluations may facilitate the wider legal acceptability of AI. In developing countries such as India, sophisticated forensic infrastructure is unattainable for significant portions of the population due to the healthcare system's emphasis on fundamental service provision. Establishing high-tech forensic labs in such situations poses a tremendous challenge for legislators. To tackle this issue, AI integration in forensic medicine could commence as pilot projects in specific urban locations. After thorough assessment of their efficacy, these projects may be expanded incrementally, harmonizing innovation with accessibility.

Artificial intelligence possesses transformative capabilities in forensic medicine, especially in autopsy and toxicological evaluations. Nonetheless, its execution depends on surmounting critical obstacles, including the accessibility of high-quality data for machine training. Forensic specialists globally must cooperate to furnish AI systems with extensive datasets, encompassing meticulous autopsy results, annotated imagery, and statistical data on biomarkers. This approach will be time-consuming and necessitate frequent revisions to maintain relevance and precision. Notwithstanding these preliminary obstacles, the incorporation of AI into forensic medicine offers significant benefits. By integrating classic morphological methods with sophisticated computational tools, AI can improve the accuracy and efficiency of forensic investigations. In the future, AI may become essential to forensic and toxicological practices, enhancing the precision of medicolegal conclusions. The legal recognition of AI-generated findings continues to be a significant concern. Courts may not regard such comments as definitive evidence but may employ them as ancillary information. Instructing the judiciary on the operational procedures of AI and promoting expert validation of AI-generated conclusions will be essential for its incorporation into the judicial system. For developing nations, implementing AI-assisted forensic methods as pilot projects in designated centers presents a practical strategy. A gradual extension, guided by the effectiveness and results of these pilot programs, can progressively close the divide between advanced forensic skills and broad accessibility.

Common Applications of AI in Forensic Toxicology:

Khanagar S.B. et al. examine the prospective utilization of artificial intelligence (AI) in mandibular reconstruction, emphasizing the application of AI models derived from artificial neural networks (ANN) and convolutional neural networks (CNN) [24]. These models have exhibited promising outcomes, demonstrating accuracy and precision akin to expert-level evaluations, which is especially advantageous in the identification of victims in mass disasters [23]. CNN, a deep learning system, operates by utilizing diverse attributes to differentiate input images from one another. These networks replicate the processing capabilities of the human brain, enhancing recognition, particularly when many image slices are utilized, hence offering a 3D feature and improving the quality of image reconstruction [25,26]. Forensic anthropologists encounter the formidable challenge of handling extensive anthropometric data, with weariness, subjectivity, and methodological constraints potentially leading to inaccuracies. Artificial intelligence can mitigate these inaccuracies by automating data processing, emulating human brain networks devoid of weariness or emotional bias, and providing constant, objective analysis. The application of AI in person identification (PI) during the COVID-19 epidemic would have been especially advantageous, considering the significant number of fatalities and unrecognized corpses. Matsuda S. and Yoshimura H. (2022) propose that conventional anthropological methods, including facial feature analysis (e.g., hair, eye color, scars, tattoos) and DNA and fingerprint analysis, may be augmented or entirely substituted by sophisticated AI techniques that evaluate diverse physiological parameters, such as retinal models and fingerprints. This trend toward AI is already being applied in institutions prioritizing data security, however the ethical implications of applying AI to real persons remain a subject of dispute [27]. Notwithstanding these advancements, facial recognition continues to be the second most prevalent technique for personal identification, following fingerprinting. Although artificial intelligence has progressed considerably, its dependence on image databases for training still requires human participation in the development and validation of these systems. Challenges connected to infrastructure and the biometric resources available to the public remain important impediments for widespread implementation [28][29].

Ballistic Expertise and Additional Factors of the Shooting

Upon the discharge of a bullet from a handgun, it possesses distinctive microscopic residues, commonly known as "ballistic fingerprints." AI can aid specialists in identifying gunpowder and cartridge residues, and by analyzing these traces against a database using image processing, so obviating the necessity for human involvement. Contemporary algorithms can illuminate residues from shooting, detect explosions within the barrel, and identify alterations induced by shock waves, so assisting in the classification of the firearm's make and caliber [30].

Traumatic Injuries—Bruise Color Recognition

Ecchymoses (bruises) exhibit a color progression during the healing process, transitioning from red to blue-violet, then green, brown, and ultimately yellow as hemoglobin degrades and is supplanted by biliverdin, bilirubin, and hemosiderin. Forensic practitioners generally evaluate the age of bruises through visual examination of color alterations. AI-driven algorithms provide a more accurate approach to assessing the time of traumatic injuries. These algorithms eradicate the subjective variability intrinsic to human evaluations, yielding more precise estimations of the time intervals between trauma and injury occurrence [31].

Determination of the Postmortem Interval (PMI)

Estimating the postmortem interval (PMI) is a standard yet essential component of forensic investigations. Artificial intelligence has considerably improved the domain of PMI estimation, especially by facilitating the examination of biomarkers present in biological fluids, including blood and urine. Collection of blood from the femoral vein is advised for the assessment of biochemical constituents, including lactate dehydrogenase (LDH), aspartate aminotransferase (AST), triglycerides, cholesterol, and pH, as these indicators can assist in determining the time of death. The concentrations of these biomarkers fluctuate as the body undergoes decomposition, with alterations directly linked to the elapsed time from death. Zou Y. et al. observe that AI technology is swiftly advancing for data processing and is already employed by several researchers as a standard technique for assessing PMI [32-33]. Moreover, artificial intelligence, when integrated with next-generation sequencing (NGS), can analyze the cadaveric microbiome, yielding significant insights into microbial community composition, ecological function, and diversity, thereby improving the precision of post-mortem interval estimations in forensic medicine [34].

Forensic Toxicology

The incorporation of artificial intelligence (AI) into forensic toxicology has significant potential, especially in broadening search parameters and establishing links between extensive databases to detect harmful chemicals, medicines, and other metabolites. By 2020, AI-assisted automated toxicological analysis facilitated the identification of more than 160 million organic and inorganic compounds in the Chemical Abstracts Service (CAS) database, aiding in both qualitative and quantitative evaluations. Helma C. et al. (2020) discussed how human errors, commonly occurring during classic spectrophotometric analyses or employing neutron and high-performance liquid chromatography (HPLC), can be minimized with the application of AI. AI improves the reliability of data sets for sample analysis, so enhancing the precision, efficiency, and cost-effectiveness of forensic investigations, potentially minimizing human error and optimizing the analytical process [35-36].

Sperm Identification

The identification of sperm is essential in forensic investigations, especially in sexual assault cases, when its presence or absence serves as critical evidence. In other cases, samples may contain minimal or no sperm, rendering manual slide scanning with optical microscopes a laborious and time-intensive endeavor. Convolutional neural networks (CNN), especially those utilizing the VGG19 architecture and its derivatives, can facilitate this process autonomously. These AI models can substantially decrease scanning durations by precisely detecting sperm in microscopic images, even in instances with limited sperm visibility, thus expediting forensic inquiries and enhancing efficiency [37].

Crime Scene Reconstruction

The procedure for collecting and reconstructing crime scene evidence, usually requiring forensic pathologists, can be resource-demanding and susceptible to human limits. Artificial intelligence can facilitate the analysis of input data, such photos of the deceased or adjacent objects, to generate comprehensive reconstructions. Through data processing, AI can extract pertinent information and produce video animations that depict possible crime scenarios, providing new insights into the circumstances of a death. This method improves the precision of crime scene investigation, minimizing subjectivity and the time needed for hand reconstruction [38].

Virtual Autopsy

The integration of AI and virtual autopsy signifies a substantial progression in forensic pathology. Virtual autopsies utilize AI to apply CT or MRI scans for capturing intricate images of the body, thereafter processed to identify pathologies, fractures, severe traumas, and diverse forms of inflammation. The AI analyzes these photos, contrasts them with an extensive database, and produces its own evaluation of the organ pathology and possible cause of death. This technology can deliver essential information regarding firearm-related injuries, including the estimation of bullet caliber through the analysis of entrance wounds in flat bones. Furthermore, virtual autopsy facilitates the collecting of biological samples, supporting forensic doctors in formulating better diagnoses and drawing more valid conclusions about the cause of death [39].

Advancements in Artificial Intelligence in Forensic Medicine and Pathology

The incorporation of artificial intelligence (AI) in forensic medicine is nascent, however it possesses considerable potential to augment medical practices. AI is expected to advance, assisting experts in enhancing their techniques and increasing diagnostic precision. In forensic medicine, AI is currently employed in various critical areas, which can be classified as follows: (1) Enhancing the forensic pathologist's capacity to render accurate anatomopathological diagnoses both macroscopically and through supplementary examinations; (2) diminishing the impact of subjective judgment and alleviating fatigue, two factors intrinsically linked to human frailty; (3) lowering costs in forensic investigations by allowing AI to deliver earlier, more dependable conclusions, thereby obviating the necessity for redundant tests and reducing the potential for human errors; (4) promoting the development of electronic data storage systems that surpass conventional methods, thereby addressing the challenges associated with physical storage devices such as USB drives and hard disks, which are susceptible to damage and data loss. Notwithstanding the gains provided by AI, its legal status continues to be examined, especially about its acceptability as definitive proof in judicial proceedings. Although AI systems exhibit greater objectivity and precision than human analysis by mitigating human biases, their integration into legal proceedings remains incomplete. Despite the potential of AI algorithms to deliver more precise evaluations, their conclusions may not be regarded as definitive evidence in forensic reports. As AI becomes further integrated into routine medical practice, its legitimacy is expected to enhance, resulting in wider acceptance. Gerke S. et al. (2020) highlight that AI encounters problems with ethics, data privacy, transparency, cybersecurity, algorithmic accuracy, and the confidentiality of medical information [40].

AI's Role in Medical Malpractice Evaluation

The application of artificial intelligence in assessing medical negligence cases is an emerging area of study. Artificial intelligence can diminish the occurrence of medical errors by improving diagnostic precision, forecasting problems, and evaluating the efficacy of treatment strategies. Numerous studies have investigated the role of AI in enhancing medical practice, particularly its applications in diagnosis, prognosis, and decision-making [41-54]. Artificial intelligence algorithms can be trained to interpret medical imaging data, including X-rays, CT scans, and MRIs, facilitating the detection and diagnosis of various illnesses. These technologies have demonstrated potential in assisting medical practitioners by delivering expedited, precise diagnostic insights, thereby improving patient care and mitigating the risk of medical misconduct [55-58].

AI-Driven Personalized Treatment and Disease Management

Artificial intelligence (AI), in conjunction with pharmacogenomics, holds the potential to revolutionize personalized medicine by tailoring drug therapies based on an individual's genetic makeup and predicting potential drug–drug interactions. By analyzing medical histories and comprehensive data, AI can devise predictive treatment plans, ensuring that patients receive the most effective medications for their specific conditions [59].

Disease Monitoring and Predictive Management

AI-powered monitoring systems are increasingly being utilized to track vital patient parameters such as heart rate, glucose levels, and blood pressure. These systems can analyze the data in real time to detect early signs of complications, thus enabling proactive management of chronic conditions. In a notable study conducted in China by Weng S.F. et al. (2005-2015), machine learning algorithms applied to clinical data from over 350,000 patients significantly improved cardiovascular risk prediction, accurately identifying 355 more patients (a 7.6% increase) who developed cardiovascular disease compared to traditional prediction methods [60]. AI's ability to handle and interpret vast healthcare data sets allows clinicians to make more informed, timely decisions, enhancing patient outcomes.

Robot-Assisted Surgery

Artificial intelligence is revolutionizing surgery, especially in the treatment of acute and chronic conditions. Zhou X.Y et al. assert that AI has improved patient survival and optimized surgical results by increasing the accuracy of surgical procedures [61]. Contemporary robotic systems autonomously execute fundamental surgical procedures, including suturing and knot tying. A very advanced surgical robot has proven capable of autonomously suturing the small intestines of a pig, exceeding the manual dexterity of seasoned surgeons executing the same procedure concurrently [62-64]. This signifies the expanding capability of AI in executing progressively intricate surgical operations with enhanced accuracy.

Drug Discovery

Artificial intelligence is expediting drug discovery by facilitating the modeling of molecular interactions and the identification of molecules with therapeutic efficacy. In toxicology, deep learning models can identify patterns of drug misuse by examining data from many sources, such as social media, poison control centers, published reports, and national surveys [65]. As artificial intelligence advances, its potential in drug discovery is expected to grow, facilitating the creation of innovative therapeutics and enhancing public health results. The incorporation of artificial intelligence (AI) in forensic medicine and pathology signifies a significant enhancement in the efficiency and precision of medical investigations. Artificial intelligence technologies have exhibited significant potential in enhancing data analysis and interpretation processes. It is essential to emphasize that human expertise is vital for making critical decisions. Ensuring the quality of obtained data is essential for the maximum performance of AI. AI can only achieve its full potential in forensic applications with dependable and precise data. Artificial intelligence provides substantial advantages in the legal system, including the acceleration of evidence analysis and the improvement of investigative accuracy. However, the shift to entirely automated AI systems in forensic medicine and law will necessitate time and continuous enhancement. Although AI improves efficiency, it cannot substitute the intricate understanding and discernment that human professionals offer. Consequently, AI need to be regarded not as a replacement but as an invaluable instrument that enhances human proficiency. The continuous incorporation of AI into forensic medicine presents significant potential for social welfare and safety. By promoting collaboration between technology and human practitioners, we can fully leverage AI's potential, enhancing justice and optimizing medical service delivery. This equitable strategy guarantees that ethical standards and human supervision remain pivotal in the advancing domain of forensic medicine and pathology.

Applications in Clinical Pathology:

Artificial intelligence (AI) is revolutionizing clinical pathology by automating complex diagnostic processes, enhancing accuracy, and enabling data-driven decision-making. One of its most impactful applications is in the analysis of digital pathology images. Machine learning algorithms, particularly convolutional neural networks (CNNs), can analyze histopathological slides with high precision, detecting patterns and anomalies such as tumor margins, cell morphology, and tissue abnormalities. These tools not only reduce interobserver variability but also accelerate diagnostic timelines, thereby improving patient outcomes. For instance, AI-powered image analysis has shown exceptional promise in identifying malignancies in breast, prostate, and lung tissues, with sensitivity and specificity comparable to or exceeding that of human pathologists. AI also plays a critical role in laboratory medicine by automating routine tasks and optimizing workflows. Clinical laboratories increasingly rely on AI-driven platforms to manage highthroughput testing environments, such as hematology analyzers capable of classifying blood cells and flagging abnormalities for further investigation. Such automation minimizes manual errors, enhances operational efficiency, and reduces costs. Furthermore, AI is facilitating advancements in molecular pathology, including genomics and proteomics. By leveraging large-scale data from next-generation sequencing (NGS), AI algorithms can identify genetic mutations and biomarkers linked to various diseases, enabling personalized medicine. In the context of infectious diseases, AI models analyze pathogen genomic sequences to predict antimicrobial resistance patterns and guide treatment strategies.

In addition to diagnostics, AI is transforming predictive and prognostic modeling in clinical pathology. Predictive algorithms assess patient risk profiles based on laboratory test results and electronic health records (EHRs), aiding in the early detection of conditions such as diabetes, cardiovascular diseases, and sepsis. Prognostic models, on the other hand, estimate disease progression and patient survival, which are critical for therapeutic planning. For example, AI tools have been utilized to predict outcomes in hematological malignancies by analyzing bone marrow biopsy results alongside patient clinical data. Another transformative application is in quality assurance and standardization. AI systems continuously monitor laboratory instruments and processes, ensuring adherence to quality control standards. For instance, AI-powered tools in hematology automatically detect and rectify instrument calibration issues, minimizing downtime and ensuring consistent results. Additionally, AI supports laboratory decision systems by interpreting complex datasets and recommending test prioritizations, enabling clinicians to make informed choices efficiently. Despite its benefits, the integration of AI in clinical pathology faces challenges, including data privacy concerns, algorithm transparency, and the need for substantial training data to ensure model reliability. Moreover, the ethical implications of relying on AI for critical medical decisions necessitate regulatory frameworks and human oversight. Nevertheless, the growing incorporation of AI technologies in clinical pathology promises a future where precision diagnostics, operational efficiency, and personalized patient care converge seamlessly. As the field continues to evolve, the collaboration between pathologists and AI will remain central to harnessing the full potential of this technology.

Opportunities and Challenges:

Artificial intelligence (AI) has created transformative opportunities in forensic and clinical pathology by enhancing diagnostic precision, operational efficiency, and overall healthcare delivery. However, its adoption is accompanied by significant challenges, particularly regarding data security, ethical considerations, and integration into existing healthcare frameworks. Understanding these opportunities and challenges is crucial for leveraging AI's potential while ensuring its responsible and effective application.

Opportunities

AI presents immense potential in improving diagnostic accuracy and efficiency. In clinical pathology, advanced machine learning algorithms can analyze vast datasets from histopathological images, molecular diagnostics, and laboratory tests. For instance, convolutional neural networks (CNNs) excel in detecting subtle histopathological patterns, such as early cancerous lesions, that might escape human observation. These tools reduce interobserver variability and enable faster, more consistent diagnostics, which are essential for conditions requiring rapid intervention. Furthermore, in forensic pathology, AI can automate the analysis of complex datasets, such as those from virtual autopsies using CT or MRI scans, offering detailed insights into causes of death, trauma, and pathology with unprecedented precision. AI's predictive modeling capabilities are another significant opportunity. By integrating electronic health records (EHRs), genetic data, and real-time patient monitoring, AI algorithms can forecast disease progression and treatment outcomes, enabling personalized medicine. For example, AI-driven platforms can predict cardiovascular risks or the likelihood of sepsis using historical and real-time clinical data. In forensic pathology, predictive analytics can assist in crime scene reconstruction and risk profiling, enhancing investigative accuracy and judicial processes.

Operational efficiency is another area where AI has proven transformative. AI-powered systems streamline laboratory workflows by automating routine tasks, such as blood cell classification and genetic sequencing analysis. These systems reduce manual errors, save time, and enable laboratories to handle higher volumes of tests without compromising quality. Additionally, AI aids in resource optimization by identifying areas of inefficiency, thereby lowering costs and improving service delivery. Forensic applications include automating the identification of toxic substances, drugs, and metabolites, significantly reducing the time and resources required for toxicological analysis. AI also fosters innovation in drug discovery and precision medicine. In clinical pathology, AI accelerates drug discovery by modeling molecular interactions and identifying promising therapeutic candidates. In forensic toxicology, deep learning models analyze diverse datasets, including social media trends and poison control logs, to detect emerging patterns in substance abuse. These insights not only guide therapeutic development but also inform public health strategies.

Challenges

Despite these opportunities, the integration of AI into forensic and clinical pathology is fraught with challenges. One primary issue is the quality and availability of data. AI algorithms require vast amounts of high-quality, annotated data to perform effectively. In pathology, the variability in staining techniques, imaging modalities, and sample preparation can lead to inconsistent data quality, impacting model accuracy. In forensic pathology, limited access to diverse datasets—due to legal, ethical, or logistical constraints—hinders the development of robust AI tools. Another critical challenge is data security and privacy. Clinical and forensic data often contain sensitive information, making it a prime target for cyberattacks. Ensuring the confidentiality, integrity, and availability of data is paramount, yet many AI systems lack adequate security measures. For instance, the use of cloud-based platforms for AI analysis exposes data to potential breaches, necessitating stringent encryption and access control mechanisms. Ethical considerations also pose significant challenges. The use of AI in forensic pathology raises concerns about bias and accountability. Algorithms trained on non-representative datasets may produce biased outcomes, potentially leading to unjust legal decisions. Similarly, in clinical pathology, over-reliance on AI could erode patient trust, especially if decisions made by AI systems lack transparency or are difficult to explain. The "black-box" nature of many AI models complicates accountability, as it is often unclear how specific conclusions are reached. Regulatory and legal challenges further complicate AI integration. The absence of standardized frameworks for validating AI tools in pathology makes it difficult to ensure their reliability and safety. For forensic applications, the legal admissibility of AI-derived evidence remains contentious, as courts are hesitant to accept findings that cannot be easily verified or understood by human experts. Regulatory bodies must establish clear guidelines to address these issues while fostering innovation.

Lastly, the human factor presents both an opportunity and a challenge. While AI can augment human expertise, it cannot replace it. Effective implementation requires significant investment in training pathologists and forensic professionals to work alongside AI systems. Resistance to change, coupled with concerns about job displacement, can hinder adoption. Moreover, ensuring that AI complements rather than supplants human judgment is crucial to maintaining ethical and professional standards in pathology. The opportunities presented by AI in forensic and clinical pathology are transformative, spanning enhanced diagnostics, predictive modeling, operational efficiency, and innovation. However, the challenges associated with data quality, security, ethical considerations, regulatory frameworks, and human integration must be addressed to realize its full potential. A balanced approach that emphasizes collaboration between AI systems and human expertise, supported by robust regulatory and ethical frameworks, is essential for harnessing AI's capabilities responsibly. By addressing these challenges, AI can become an indispensable tool in advancing the fields of forensic and clinical pathology, ultimately improving patient care and judicial outcomes.

Conclusion:

Artificial Intelligence (AI) has emerged as a transformative tool in forensic medicine and toxicology, offering unprecedented opportunities to improve the precision, efficiency, and reliability of processes critical to legal and investigative contexts. Its applications span diverse areas, including automated data analysis, virtual autopsies, predictive toxicology, and omics-based biomarker identification. These technologies not only enhance the accuracy of findings but also reduce human error and optimize resource allocation, addressing some of the longstanding challenges in forensic practice. Despite these advancements, the integration of AI in forensic toxicology is not without challenges. The technology heavily relies on high-quality datasets to ensure robust and reliable outcomes. However, the availability of such data can be limited due to privacy concerns, variations in forensic standards across regions, and the sensitive nature of forensic investigations. Ethical issues surrounding AI usage, including biases in algorithms, data ownership, and the potential for misuse, further complicate its adoption. Additionally, implementing AI systems demands substantial investments in infrastructure, training, and interdisciplinary collaboration, making it a resource-intensive endeavor. To fully harness AI's potential in forensic medicine and toxicology, a balanced approach is required. This includes developing standardized protocols for data sharing and algorithm validation, implementing robust ethical guidelines, and fostering cross-disciplinary partnerships among forensic scientists, data analysts, and legal professionals. Governments and institutions must also invest in capacity-building initiatives to train professionals in both AI and forensic methodologies, ensuring seamless integration and effective utilization of these tools. In conclusion, AI is poised to revolutionize forensic toxicology by addressing critical gaps and enabling advancements that were once considered unattainable. However, its success depends on overcoming ethical, technical, and operational barriers. A collaborative effort among stakeholders is essential to ensure AI is leveraged responsibly, enhancing the credibility and trustworthiness of forensic investigations. By aligning technological innovation with ethical integrity and practical feasibility, AI can significantly contribute to the evolution of forensic medicine and toxicology in the era of the Fourth Industrial Revolution.

References:

1. Narasimhan G, Krishnan R, Krishnan A. Fourth Industrial Revolution and Business Dynamics: Issues and Implications . Singapore: Palgrave Macmillan; 2021. Industrial revolution 4.0: transformation of job market; pp. 259–268.
2. Artificial intelligence in disease diagnosis: a systematic literature review, synthesizing framework and future research agenda. Kumar Y, Koul A, Singla R, Ijaz MF. J Ambient Intell Humaniz Comput. 2022;13:1–28. doi: 10.1007/s12652-021-03612-z.
3. Meetali S, Sachan D, Parthasarathi R. Artificial Intelligence in Medicine. Cham: Springer; 2021. Artificial intelligence in clinical toxicology; pp. 1–15.
4. Forensic toxicology and its relevance with criminal justice delivery system in India. Yadav M, Tiwari A. Forensic Res Criminol Int J. 2017;4:122–128.
5. Aggrawal A. Avichal Publication Company New Delhi. New Delhi: Avichal Publication Company; 2014. Textbook of forensic medicine and toxicology; pp. 545–546.
6. Machine learning enhanced virtual autopsy. O'Sullivan S, Holzinger A, Zatloukal K, Saldiva P, Sajid MI, Wichmann D. Autops Case Rep. 2017;7:3–7. doi: 10.4322/acr.2017.037.
7. Use of advanced artificial intelligence in forensic medicine, forensic anthropology and clinical anatomy. Thurzo A, Kosnáčová HS, Kurilová V, et al. Healthcare (Basel) 2021;9:1545. doi: 10.3390/healthcare9111545.
8. Personal identification with artificial intelligence under COVID-19 crisis: a scoping review. Matsuda S, Yoshimura H. Syst Rev. 2022;11:7. doi: 10.1186/s13643-021-01879-z.
9. Biometrics in forensic identification: applications and challenges. Saini M, Kapoor AK. https://www.hilarispublisher.com/open-access/biometrics-in-forensic-identification-applications-and-challenges-2472-1026-1000108.pdf J Forensic Med. 2016;1:108.
10. Sperm hunting on optical microscope slides for forensic analysis with deep convolutional networks - a feasibility study. Golomingi R, Haas C, Dobay A, Kottner S, Ebert L. Forensic Sci Int Genet. 2022;56:102602. doi: 10.1016/j.fsigen.2021.102602.
11. Georgieva L, Dimitrova T, Stoyanov I. CompSysTech. Varna: Bulgarian Chapter of ACM; 2005. Computer-aided system for the bruise color's recognition; pp. 0–6.

12. Survey on prediction of post mortem interval using artificial intelligence in forensic examination. Ramprabhu K, Fatangare S. https://www.irjet.net/archives/V7/i5/IRJET-V7I51098.pdf IRJET. 2020;7:5760–5763.
13. Artificial intelligence in prediction of postmortem interval (PMI) through blood biomarkers in forensic examination-a concept. Hachem M, Sharma BK. Amity International Conference on Artificial Intelligence (AICAI) 2019:255–258.
14. Knowledge discovery and data mining in toxicology. Helma C, Gottmann E, Kramer S. Stat Methods Med Res. 2000;9:329–358. doi: 10.1177/096228020000900403.
15. Artificial intelligence in radiology. Hosny A, Parmar C, Quackenbush J, Schwartz LH, Aerts HJ. Nat Rev Cancer. 2018;18:500–510. doi: 10.1038/s41568-018-0016-5.
16. Agrebi S, Larbi A. Artificial Intelligence in Precision Health: From concept to applications. London: Academic Press; 2020. Use of artificial intelligence in infectious diseases; pp. 415–438.
17. Artificial intelligence in drug discovery and development. Paul D, Sanap G, Shenoy S, Kalyane D, Kalia K, Tekade RK. Drug Discov Today. 2021;26:80–93. doi: 10.1016/j.drudis.2020.10.010.
18. Omics era in forensic medicine: towards a new age. Akçan R, Taştekin B, Yildirim MŞ, Aydogan HC, Sağlam N. Turk J Med Sci. 2020;50:1480–1490. doi: 10.3906/sag-1912-197.
19. Simultaneous time course analysis of multiple markers based on DNA microarray in incised wound in skeletal muscle for wound aging. Gaballah MH, Fukuta M, Maeno Y, et al. Forensic Sci Int. 2016;266:357–368. doi: 10.1016/j.forsciint.2016.06.027.
20. Identifying molecular biomarkers for diseases with machine learning based on integrative omics. Shi K, Lin W, Zhao XM. IEEE/ACM Trans Comput Biol Bioinform. 2021;18:2514–2525. doi: 10.1109/TCBB.2020.2986387.
21. Cutaneous (tPA) and skeletal (TnI) mRNA as markers of aging in contused wound. Ibrahim SF, Issak M, Bayoumy AA, El-Fatah DS. J Forensic Sci. 2016;61:1007–1010. doi: 10.1111/1556-4029.13072.
22. Machine learning and integrative analysis of biomedical big data. Mirza B, Wang W, Wang J, Choi H, Chung NC, Ping P. Genes (Basel) 2019;10 doi: 10.3390/genes10020087.
23. Mohammad, N.; Ahmad, R.; Kurniawan, A.; Mohd Yusof, M.Y.P. Applications of Contemporary Artificial Intelligence Technology in Forensic Odontology as Primary Forensic Identifier: A Scoping Review. *Front. Artif. Intell.* **2022**, *5*, 1049584.
24. Khanagar, S.B.; Vishwanathaiah, S.; Naik, S.; Al-Kheraif, A.; Devang Divakar, D.; Sarode, S.C.; Bhandi, S.; Patil, S. Application and Performance of Artificial Intelligence Technology in Forensic Odontology—A Systematic Review. *Leg. Med.* **2021**, *48*, 101826.
25. Thurzo, A.; Kosnáčová, H.S.; Kurilová, V.; Kosmeľ, S.; Beňuš, R.; Moravanský, N.; Kováč, P.; Kuracinová, K.M.; Palkovič, M.; Varga, I. Use of Advanced Artificial Intelligence in Forensic Medicine, Forensic Anthropology and Clinical Anatomy. *Healthcare* **2021**, *9*, 1545.
26. Niño-Sandoval, T.C.; Guevara Pérez, S.V.; González, F.A.; Jaque, R.A.; Infante-Contreras, C. Use of Automated Learning Techniques for Predicting Mandibular Morphology in Skeletal Class I, II and III. *Forensic Sci. Int.* **2017**, *281*, 187.e1–187.e7.
27. Matsuda, S.; Yoshimura, H. Personal Identification with Artificial Intelligence under COVID-19 Crisis: A Scoping Review. *Syst. Rev.* **2022**, *11*, 7.
28. Nguyen, D.; Park, K. Body-Based Gender Recognition Using Images from Visible and Thermal Cameras. *Sensors* **2016**, *16*, 156.

29. Massimo, L. From Fingers to Faces: Visual Semiotics and Digital Forensics. *Int. J. Semiot. Law* **2021**, *34*, 579–599.
30. Bobbili, R.; Ramakrishna, B.; Madhu, V. An Artificial Intelligence Model for Ballistic Performance of Thin Plates. *Mech. Based Des. Struct. Mach.* **2023**, *51*, 327–338.
31. Georgieva, L.; Dimitrova, T.; Stoyanov, I. *Computer-Aided System for the Bruise Color's Recognition*; Bulgarian Chapter: Sofia, Bulgaria, 2005; pp. 1–6.
32. Hachem, M.; Sharma, B.K. Artificial Intelligence in Prediction of PostMortem Interval (PMI) through Blood Biomarkers in Forensic Examination–A Concept. In Proceedings of the 2019 Amity International Conference on Artificial Intelligence (AICAI), Dubai, United Arab Emirates, 4–6 February 2019; IEEE: Piscataway, NJ, USA, 2019.
33. Zou, Y.; Zhuang, C.; Fang, Q.; Li, F. Big Data and Artificial Intelligence: New Insight into the Estimation of Postmortem Interval. *Fa Yi Xue Za Zhi* **2020**, *36*, 86–90.
34. Wang, Z.; Zhang, F.; Wang, L.; Yuan, H.; Guan, D.; Zhao, R. Advances in Artificial Intelligence-Based Microbiome for PMI Estimation. *Front. Microbiol.* **2022**, *13*, 1034051.
35. Gasteiger, J. Chemistry in Times of Artificial Intelligence. *Chemphyschem* **2020**, *21*, 2233–2242.
36. Helma, C. Data Mining and Knowledge Discovery in Predictive Toxicology. *SAR QSAR Environ. Res.* **2004**, *15*, 367–383.
37. Golomingi, R.; Haas, C.; Dobay, A.; Kottner, S.; Ebert, L. Sperm Hunting on Optical Microscope Slides for Forensic Analysis with Deep Convolutional Networks—A Feasibility Study. *Forensic Sci. Int. Genet.* **2022**, *56*, 102602.
38. Gupta, S.; Sharma, V. Artificial intelligence in forensic science. artificial intelligence in forensic science. *Int. Res. J. Eng. Technol.* **2020**, *7*, 7181–7184.
39. Sullivan, S.O.; Holzinger, A.; Zatloukal, K.; Saldiva, P.; Sajid, M.I.; Wichmann, D. Machine Learning Enhanced Virtual Autopsy. *Autops. Case Rep.* **2017**, *7*, 3–7.
40. Gerke, S.; Minssen, T.; Cohen, G. Ethical and Legal Challenges of Artificial Intelligence-Driven Healthcare. In *Artificial Intelligence in Healthcare*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 295–336.
41. Santin, M.; Brama, C.; Théro, H.; Ketheeswaran, E.; El-Karoui, I.; Bidault, F.; Gillet, R.; Gondim Teixeira, P.; Blum, A. Detecting Abnormal Thyroid Cartilages on CT Using Deep Learning. *Diagn. Interv. Imaging* **2019**, *100*, 251–257.
42. Qiu, S.; Joshi, P.S.; Miller, M.I.; Xue, C.; Zhou, X.; Karjadi, C.; Chang, G.H.; Joshi, A.S.; Dwyer, B.; Zhu, S.; et al. Development and Validation of an Interpretable Deep Learning Framework for Alzheimer's Disease Classification. *Brain* **2020**, *143*, 1920–1933.
43. Salazar, L.; Vasquez, J.F.; Torres, C.L.B.; Camacho, J.; Turbay, C.I.; Garnica, D.E.; Torralba, F.; Isaza-Restrepo, D.; Alferez, S. Prediction of Acute Complications in Patients with Myocardial Infarction Using Artificial Intelligence. *J. Am. Coll. Cardiol.* **2023**, *81*, 2404.
44. Attia, Z.I.; Kapa, S.; Yao, X.; Lopez-Jimenez, F.; Mohan, T.L.; Pellikka, P.A.; Carter, R.E.; Shah, N.D.; Friedman, P.A.; Noseworthy, P.A. Prospective validation of a deep learning electrocardiogram algorithm for the detection of left ventricular systolic dysfunction. *J. Cardiovasc. Electrophysiol.* **2019**, *30*, 668–674.
45. Alsharqi, M.; Woodward, W.J.; Mumith, J.A.; Markham, D.C.; Upton, R.; Leeson, P. Artificial intelligence and echocardiography. *Echo Res. Pract.* **2018**, *5*, R115–R125.
46. Zhang, Y.-H.; Guo, L.-J.; Yuan, X.-L.; Hu, B. Artificial Intelligence-Assisted Esophageal Cancer Management: Now and Future. *World J. Gastroenterol.* **2020**, *26*, 5256–5271.

47. Rajpurkar, P.; Chen, E.; Banerjee, O.; Topol, E.J. AI in Health and Medicine. *Nat. Med.* **2022**, *28*, 31–38.
48. Young, A.T.; Xiong, M.; Pfau, J.; Keiser, M.J.; Wei, M.L. Artificial Intelligence in Dermatology: A Primer. *J. Investig. Dermatol.* **2020**, *140*, 1504–1512.
49. Dick, V.; Sinz, C.; Mittlböck, M.; Kittler, H.; Tschandl, P. Accuracy of Computer-Aided Diagnosis of Melanoma: A Meta-analysis. *JAMA Dermatol.* **2019**, *155*, 1291–1299.
50. Pedersen, M.; Verspoor, K.; Jenkinson, M.; Law, M.; Abbott, D.F.; Jackson, G.D. Artificial intelligence for clinical decision support in neurology. *Brain Commun.* **2020**, *2*, fcaa096.
51. Rathi, S.; Tsui, E.; Mehta, N.; Zahid, S.; Schuman, J.S. The Current State of Teleophthalmology in the United States. *Ophthalmology* **2017**, *124*, 1729–1734.
52. Kröner, P.T.; Engels, M.M.; Glicksberg, B.S.; Johnson, K.W.; Mzaik, O.; van Hooft, J.E.; Wallace, M.B.; El-Serag, H.B.; Krittanawong, C. Artificial intelligence in gastroenterology: A state-of-the-art review. *World J. Gastroenterol.* **2021**, *27*, 6794–6824.
53. Idowu, I.O.; Fergus, P.; Hussain, A.; Dobbins, C.; Khalaf, M.; Eslava, R.V.C.; Keight, R. Artificial Intelligence for Detecting Preterm Uterine Activity in Gynecology and Obstetric Care. In Proceedings of the 2015 IEEE International Conference on Computer and Information Technology; Ubiquitous Computing and Communications; Dependable, Autonomic and Secure Computing; Pervasive Intelligence and Computing, Liverpool, UK, 26–28 October 2015; pp. 215–220.
54. Sone, K.; Toyohara, Y.; Taguchi, A.; Miyamoto, Y.; Tanikawa, M.; Uchino-Mori, M.; Iriyama, T.; Tsuruga, T.; Osuga, Y. Application of artificial intelligence in gynecologic malignancies: A review. *J. Obstet. Gynaecol. Res.* **2021**, *47*, 2577–2585.
55. Hosny, A.; Parmar, C.; Quackenbush, J.; Schwartz, L.H.; Aerts, H.J.W.L. Artificial intelligence in radiology. *Nat. Rev. Cancer* **2018**, *18*, 500–510
56. Chen, H.; Zheng, Y.; Park, J.H.; Heng, P.A.; Zhou, S.K. Iterative Multi-Domain Regularized Deep Learning for Anatomical Structure Detection and Segmentation from Ultrasound Images. In Proceedings of the International Conference on Medical Image Computing and Computer-Assisted Intervention, Athens, Greece, 17–21 October 2016; pp. 487–495. [
57. Ghafoorian, M.; Karssemeijer, N.; Heskes, T.; van Uden, I.W.M.; Sanchez, C.I.; Litjens, G.; de Leeuw, F.E.; van Ginneken, B.; Marchiori, E.; Platel, B. Location Sensitive Deep Convolutional Neural Networks for Segmentation of White Matter Hyperintensities. *Sci. Rep.* **2017**, *7*, 5110.
58. Wang, H.; Zhou, Z.; Li, Y.; Chen, Z.; Lu, P.; Wang, W.; Liu, W.; Yu, L. Comparison of machine learning methods for classifying mediastinal lymph node metastasis of non-small cell lung cancer from 18F-FDG PET/CT images. *EJNMMI Res.* **2017**, *7*, 11.
59. Davenport, T.; Kalakota, R. The Potential for Artificial Intelligence in Healthcare. *Future Healthc. J.* **2019**, *6*, 94–98.
60. Weng, S.F.; Reps, J.; Kai, J.; Garibaldi, J.M.; Qureshi, N. Can machine learning improve cardiovascular risk prediction using routine clinical data? *PLoS ONE* **2017**, *12*, e0174944.
61. Zhou, X.Y.; Guo, Y.; Shen, M.; Yang, G.Z. Application of artificial intelligence in surgery. *Front. Med.* **2020**, *14*, 417–430.
62. Hu, Y.; Zhang, L.; Li, W.; Yang, G.Z. Robotic Sewing and Knot Tying for Personalized Stent Graft Manufacturing. In Proceedings of the 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Madrid, Spain, 1–5 October 2018; pp. 754–760.
63. Hu, Y.; Li, W.; Zhang, L.; Yang, G.Z. Designing, prototyping, and testing a flexible suturing robot for transanal endoscopic microsurgery. *IEEE Robot. Autom. Lett.* **2019**, *4*, 1669–1675.

64. Shademan, A.; Decker, R.S.; Opfermann, J.D.; Leonard, S.; Krieger, A.; Kim, P.C.W. Supervised autonomous robotic soft tissue surgery. *Sci. Transl. Med.* **2016**, *8*, 337ra64.
65. Poalelungi, D.G.; Musat, C.L.; Fulga, A.; Neagu, M.; Neagu, A.I.; Piraianu, A.I.; Fulga, I. Advancing Patient Care: How Artificial Intelligence Is Transforming Healthcare. *J. Pers. Med.* **2023**, *13*, 1214

علم السموم الجنائي في العصر الحديث: التغلب على التحديات واستغلال الاتجاهات الجديدة من خلال استخدام الذكاء الاصطناعي

المستخلص:

الخلفية :أدت الثورة الصناعية الرابعة إلى تحقيق تطورات تكنولوجية تحولية، حيث يلعب الذكاء الاصطناعي (AI) دورًا محوريًا في مختلف الصناعات. وفي مجال علم السموم الجنائي، يوفر الذكاء الاصطناعي إمكانيات غير مسبوقة لتحسين دقة وكفاءة تحليل العينات البيولوجية، والتحقيقات الجنائية، وتشريح الجثث الطبي الشرعي. ورغم وعوده، تعيق التحديات مثل المخاوف الأخلاقية، وقضايا خصوصية البيانات، والمتطلبات البنية التحتية انتشاره الواسع.

الهدف :تستكشف هذه المراجعة الدور التحويلي للذكاء الاصطناعي في الطب الشرعي وعلم السموم الجنائي، مع التركيز على تطبيقاته وفوائده المحتملة والتحديات المرتبطة به. وتهدف إلى تحديد التطورات الأساسية المطلوبة للاستفادة الكاملة من إمكانيات الذكاء الاصطناعي في هذه المجالات.

الطرق :تم إجراء مراجعة شاملة للأدبيات المتاحة، مع التركيز على التطبيقات الحالية والناشئة للذكاء الاصطناعي في الطب الشرعي وعلم السموم الجنائي. وركزت المراجعة على دور الذكاء الاصطناعي في تحليل البيانات، وأبحاث "الأوميكس"، وتشريح الجثث الشرعي، والتقييمات السمّية. كما تم تقييم القيود والمخاوف الأخلاقية واحتياجات البنية التحتية.

النتائج :تُعزز تقنيات الذكاء الاصطناعي التحقيقات الجنائية من خلال أتمتة المهام الشاقة، وزيادة دقة التشخيص، وتمكين التحليلات التنبؤية. وتشمل التطبيقات التشريح الافتراضي، وتقدير عمر الإصابات باستخدام بيانات الأوميكس، وتحديد السموم الجديدة. ومع ذلك، تشمل القيود الاعتماد على مجموعات بيانات عالية الجودة، والمخاوف الأخلاقية، والحاجة إلى استثمارات كبيرة في البنية التحتية والتعاون بين التخصصات.

الخاتمة :يُحدث الذكاء الاصطناعي ثورة في علم السموم الجنائي والطب الشرعي، حيث يقدم حلولًا مبتكرة للتغلب على التحديات الطويلة الأمد. وعلى الرغم من أنه يعزز الكفاءة والدقة والموثوقية، إلا أن تكامله يتطلب مواجهة العوائق الأخلاقية والتكنولوجية والتشغيلية. التعاون بين الجهات المعنية ضروري لضمان أن يكمل الذكاء الاصطناعي الخبرة البشرية، مما يعزز الثقة والمصداقية في الممارسات الجنائية.

الكلمات المفتاحية :الذكاء الاصطناعي، علم السموم الجنائي، التشريح الطبي الشرعي، بيانات الأوميكس، التحديات الأخلاقية، الثورة الصناعية الرابعة، التعرف البيومتري.