

Forensic science: Tech-driven advancements and challenges.

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Introduction

Forensic science continually adapts to incorporate new methodologies and address evolving challenges, ensuring the integrity and reliability of evidence in legal contexts. A core area of development is DNA analysis, particularly as it pertains to saliva samples. This review delves into the complexities of DNA analysis from saliva in forensic investigations, covering common challenges like low DNA quantity and inhibition. It also explores recent advancements in saliva detection and DNA extraction methods, envisioning the future role of salivary microbiome analysis in distinguishing bodily fluids and estimating post-mortem interval [1].

The landscape of forensic toxicology is significantly shaped by the emergence of new psychoactive substances (NPS). This review highlights the substantial analytical challenges faced by forensic toxicologists in this domain, including the rapid appearance of novel compounds and the scarcity of reference standards. It further addresses the intricate nature of detection and quantification within biological matrices, underscoring the critical need for advanced analytical techniques and robust international collaboration to effectively identify and characterize these constantly evolving drugs [2].

Forensic identification relies heavily on accurate human remains reconstruction. This systematic review synthesizes recent advancements in three-dimensional facial reconstruction techniques. It details the progression from traditional methods to sophisticated digital approaches that utilize CT and surface scanning. The discussion also encompasses the persistent challenges in achieving accuracy and standardization, while highlighting emerging trends such as Artificial Intelligence (AI) and Machine Learning (ML) in improving the reliability and efficiency of these reconstructions for identifying unknown remains [3].

Ballistic evidence remains a crucial component in many investigations. This review focuses on the latest advancements in forensic ballistic identification, specifically examining automatic matching and characterization techniques for firearms and ammunition. It discusses breakthroughs in 3D imaging, digital analysis, and AI applications that are enhancing the speed and accuracy of comparing ballistic evidence. The aim is to overcome the limitations of traditional microscopic comparison methods and improve investigative

outcomes significantly [4].

Digital forensics is a rapidly expanding field where data integrity is paramount. This systematic review investigates the application of blockchain technology in digital forensics, focusing on its potential to enhance data integrity, chain of custody, and evidence traceability. It examines current research and proposed frameworks, highlighting how blockchain could revolutionize the secure handling of digital evidence. The review also identifies existing gaps and future research avenues for its practical implementation in forensic investigations [5].

Estimating the minimum post-mortem interval (PMI_{min}) is a critical aspect of forensic investigations, often relying on entomological evidence. This review explores the integration of new technologies into forensic entomology, specifically detailing how they enhance the accuracy of PMI_{min} estimations. It outlines the use of molecular techniques for insect species identification, advanced imaging for growth analysis, and environmental data loggers, illustrating how these tools provide more precise and reliable entomological evidence in criminal investigations [6].

Hair analysis offers a valuable tool in forensic toxicology for detecting drugs of abuse. This review provides an overview of the latest developments and persistent challenges in this field. It discusses improvements in analytical methodologies for detecting a wide range of substances, along with the interpretation complexities posed by external contamination and drug incorporation mechanisms. The review emphasizes the crucial role of standardized protocols to ensure the reliability and admissibility of hair testing results in legal contexts [7].

Forensic odontology contributes significantly to identification, particularly through age estimation. This article surveys the contemporary landscape of forensic odontology, with a specific focus on the evolving methodologies for age estimation using dental tissues. It discusses the strengths and limitations of various techniques, ranging from morphological analyses to advanced imaging and biochemical markers, emphasizing the need for population-specific data and sophisticated statistical models to improve accuracy and reliability in medicolegal contexts [8].

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Emerging forms of trace evidence continually expand the scope of forensic investigations. This critical review explores the burgeoning field of microplastics as trace evidence. It delves into the diverse analytical methods used for their detection, characterization, and comparison, and addresses the inherent challenges of environmental contamination and transfer. The review highlights the potential for microplastics to link suspects, victims, and crime scenes, suggesting future directions for standardized protocols and database development [9].

Visual evidence processing is undergoing a significant transformation. This review traces the evolution of forensic image analysis, detailing the shift from conventional manual techniques to sophisticated computational approaches, particularly emphasizing the transformative impact of deep learning. It covers applications in image authentication, enhancement, and object recognition, outlining how AI-driven methods are improving the accuracy and efficiency of processing visual evidence, while also addressing challenges related to data quality and interpretability [10].

Conclusion

Forensic science is constantly evolving, with recent reviews highlighting significant advancements and persistent challenges across various disciplines. One area of focus is DNA analysis, particularly from saliva, where advancements in extraction and detection methods are addressing low DNA quantity and inhibition issues, with promising future applications in salivary microbiome analysis for distinguishing bodily fluids and estimating post-mortem intervals [1]. Similarly, forensic toxicology faces complex challenges with the rapid emergence of New Psychoactive Substances (NPS), necessitating advanced analytical techniques and international collaboration to identify these ever-evolving drugs [2]. Digital forensics is seeing revolutionary changes with blockchain technology, enhancing data integrity, chain of custody, and evidence traceability, thereby securing the handling of digital evidence [5]. Technological integration is also transforming forensic entomology, where molecular techniques, advanced imaging, and environmental data loggers are improving minimum post-mortem interval estimations [6]. Advances in ballistic identification leverage 3D imaging, digital analysis, and Artificial Intelligence (AI) to enhance the speed and accuracy of comparing ballistic evidence, moving beyond traditional microscopic methods [4]. Facial reconstruction techniques are evolving from traditional to sophisticated digital approaches using CT and surface scanning, with AI and Machine Learning (ML) improving the reliability of identifying unknown remains [3]. Forensic odontology is refining age estimation from dental tissues through advanced imaging and biochemical markers, emphasizing the need

for population-specific data [8]. Hair analysis in forensic toxicology continues to improve for detecting drugs of abuse, though challenges remain with external contamination and interpretation complexities, stressing the importance of standardized protocols [7]. Furthermore, microplastics are emerging as novel trace evidence, with ongoing efforts to standardize analytical methods and establish databases to link individuals and crime scenes [9]. Finally, forensic image analysis has advanced significantly, transitioning from manual to computational approaches, with deep learning applications improving authentication, enhancement, and object recognition of visual evidence [10]. These collective efforts underscore a broad trend towards integrating advanced technologies like AI, 3D imaging, and molecular techniques to overcome traditional limitations, enhance accuracy, and ensure the reliability of forensic evidence in diverse investigative contexts.

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