GENETIC PROFILING AND RECOMBINANT PROTEINS: INNOVATIONS IN FORENSIC MEDICINE

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Relevance: The continuous growth of molecular forensic demands, driven by the increasing complexity of criminal investigations and the expansion of DNA databases, necessitates the development of analytical tools that are both highly sensitive and robust. In forensic practice, a significant proportion of biological evidence is obtained in a degraded, fragmented, or contaminated state, often due to environmental exposure, time lapse, or crime scene conditions. Such compromised samples present substantial challenges for conventional genetic profiling methods, which may fail to yield reliable results.

Recombinant proteins, produced through precise genetic engineering, have emerged as a pivotal solution to these limitations. Their enhanced specificity ensures accurate detection of target molecules, while high reproducibility supports consistent results across different laboratories and conditions. Furthermore, their adaptability enables customization for a variety of forensic applications, including DNA amplification, biomarker detection, and rapid on-site testing.

Given their capacity to operate effectively with minimal or damaged biological material, recombinant protein-based technologies hold the potential to significantly improve the reliability, efficiency, and scope of modern forensic genetic profiling. This makes them an essential innovation in addressing current and future challenges in forensic science.

The research purpose: The primary aim of this research is to conduct a comprehensive evaluation of the impact that recombinant protein-based technologies have on the key performance parameters of forensic genetic profiling, namely sensitivity, accuracy, and operational efficiency. This includes a detailed comparison of these innovative methods with conventional forensic genetic approaches, focusing on their ability to analyze minimal, degraded, or contaminated biological samples, which frequently occur in real-world investigative scenarios.

Furthermore, the study seeks to identify and critically assess the main challenges hindering the widespread adoption of recombinant protein technologies in forensic practice. These challenges encompass technical limitations, such as cost and equipment requirements, as well as procedural and legal barriers, including the lack of internationally

standardized protocols and variability in the judicial acceptance of molecular evidence obtained using novel biotechnological methods.

Finally, the research aims to outline potential strategies and future directions for integrating recombinant protein-based systems into routine forensic workflows, with an emphasis on enhancing data reliability, accelerating case resolution, and ensuring compliance with international forensic standards.

Method and styles: A systematic review of peer-reviewed studies published between 2018 and 2024 was carried out, focusing on the application of recombinant proteins in forensic genetics. The literature search included major international scientific databases, with inclusion criteria covering experimental, applied, and review papers that assessed the performance of recombinant protein-based techniques in forensic contexts.

A comparative analysis was conducted to evaluate key performance indicators—sensitivity, specificity, and processing time—by directly contrasting recombinant protein-based methods with conventional forensic genetic techniques. Where available, statistical data were extracted to quantify the degree of improvement or decline in each parameter.

In addition, the study assessed practical and legal challenges associated with the adoption of these technologies, including cost factors, equipment requirements, protocol standardization, and variability in judicial acceptance across different jurisdictions.

The analytical approach combined quantitative evaluation (using reported performance metrics) with qualitative synthesis of expert opinions and case study outcomes. This dual methodology ensured a balanced perspective, integrating measurable efficiency gains with real-world implementation considerations.

Style: Analytical and comparative, integrating both numerical data and descriptive insights from recent international research to provide a comprehensive evaluation.

Results: The analysis demonstrated that recombinant protein-based techniques enhanced the sensitivity of forensic genetic profiling by approximately 15–25% compared to conventional methods. Additionally, the use of these technologies reduced the average processing time required for analysis by 30–50%, significantly accelerating the investigative workflow.

Importantly, the rate of false-positive results (Type I errors) decreased by 5–7%, indicating an improvement in analytical accuracy and reliability. These methods also proved to be highly effective in the examination of challenging forensic samples, such as highly degraded biological material, trace-level DNA, or evidence contaminated with environmental impurities.

The findings further indicate that recombinant protein-based approaches facilitate the recovery and identification of genetic material in cases where traditional techniques

may fail, thereby expanding the operational capabilities of forensic laboratories and increasing the probability of obtaining admissible evidence in court proceedings.

Conclusions: Recombinant protein-based technologies represent a groundbreaking and transformative advancement in the field of forensic genetic profiling, offering not only substantial but also consistently reproducible improvements in key performance parameters such as sensitivity, specificity, and processing speed. By enabling the detection and analysis of even highly degraded, fragmented, or minimal biological samples — which often remain inaccessible to conventional methods — these technologies significantly expand the range of cases in which molecular-genetic evidence can be successfully obtained. This, in turn, enhances the overall scope and effectiveness of forensic investigations, increases the probability of solving complex cases, and strengthens the reliability and legal robustness of evidentiary conclusions presented in court.

An equally important advantage lies in their compatibility with the latest trends in forensic science — namely, the development of portable real-time analysis systems and the integration of artificial intelligence-driven interpretation algorithms. The synergy between recombinant protein-based assays and AI-assisted decision-making is expected to set an entirely new operational and quality standard in forensic practice over the next decade, enabling faster case resolution, reducing human error, and ensuring more consistent results across laboratories worldwide.

However, despite their promise, several critical challenges still hinder the large-scale adoption of these technologies. The high cost of recombinant reagents remains a limiting factor for many forensic laboratories, especially in developing regions. In addition, the need for specialized equipment and trained personnel creates technical and logistical barriers to implementation. Finally, the absence of internationally harmonized protocols for the forensic application of recombinant protein-based methods introduces variability in analytical outcomes and complicates cross-border legal recognition of results. Addressing these issues through coordinated research, policy development, and infrastructure investment will be essential for unlocking the full potential of recombinant proteins in modern forensic science.

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