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LEGAL, TECHNICAL, AND ETHICAL CHALLENGES IN THE USE OF BIOTECHNOLOGY FOR CRIME SCENE EXAMINATION

DESAFIOS JURÍDICOS, TÉCNICOS E ÉTICOS NA UTILIZAÇÃO DA BIOTECNOLOGIA NA ANÁLISE DE CENAS DE CRIME

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Abstract
The article examines the possibilities and prospects of using biotechnology in crime scene examination to improve the efficiency of crime investigation. Key areas of development of molecular genetic technologies are considered. The most common biochemical and immunological express tests are analyzed, allowing to identify blood, saliva and other biological fluids at the crime scene without violating the integrity of the trace. The main challenges that Russia has to face are presented, related to the high cost of the relevant equipment, the need to develop methodological recommendations and train investigators in the principles of competent handling of biological traces. A conclusion is made about the importance of an integrated approach, including the improvement of legislation, standardization of the procedure for the seizure and analysis of biological materials, as well as continuous

Resumo
O artigo examina as possibilidades e perspectivas do uso da biotecnologia na análise de cenas de crime para melhorar a eficiência das investigações criminais. São consideradas as principais áreas de desenvolvimento das tecnologias genéticas moleculares. São analisados os testes rápidos bioquímicos e imunológicos mais comuns, que permitem identificar sangue, saliva e outros fluidos biológicos na cena do crime sem violar a integridade do vestígio. São apresentados os principais desafios que a Rússia tem de enfrentar, relacionados com o elevado custo do equipamento relevante, a necessidade de desenvolver recomendações metodológicas e de formar investigadores nos princípios do manuseamento competente de vestígios biológicos. É apresentada uma conclusão sobre a importância de uma abordagem integrada, incluindo a melhoria da legislação, a padronização do procedimento de apreensão e

improvement of the skills of investigators and experts.

Keywords: Biological Traces. DNA Analysis. Crime Scene Examination. Forensic Examination. Criminalistics.

análise de materiais biológicos, bem como a melhoria contínua das competências dos investigadores e peritos.

Palavras-chave: *Vestígios Biológicos. Análise de DNA. Exame da Cena do Crime. Exame Forense. Criminalística.*

1 INTRODUCTION

The problem of effective recording, preservation and analysis of biological traces at the crime scene has long been recognized as relevant not only in Russia, but also in world practice. The use of biotechnology, combining the achievements of molecular genetics, biochemistry and immunology, is gradually becoming one of the most promising areas in forensic science, allowing for identification of a person, determination of the nature of biological traces and assessment of the mechanism of trace formation in the shortest possible time. Despite the existing research on this issue , affecting both the general concept of biotechnology (Kruchinina 2022) and the ethical aspects of their use (Santaló and Berdasco 2022), as well as individual methods for using the capabilities of biomedicine during crime scene examination (Zhumagulova *et al*. 2022), in general, it can be stated that there are a number of unresolved problems in carrying out this procedural action.

The hypothesis of this study is that the implementation of modern biotechnological solutions, supplemented by well-thought-out legal regulations and a training system, can significantly improve the effectiveness of crime scene investigations and strengthen the evidentiary base in criminal proceedings.

The objective is to study possible options for using biotechnology during the inspection of the crime scene (hereinafter referred to as the CSI), and, based on this, to identify emerging problems in the use of biotechnology during CSI, and to formulate the author's vision of ways to overcome them, including on the basis of international experience.

2 METHODS

2.1 Literature selection

To test the hypothesis put forward, an analysis of scientific publications for 2015–2023 was conducted. The materials selected were primarily from English-language scientific journals that examined issues of DNA technologies, biochemical test systems, and bioengineering methods used in crime scene examinations. When selecting sources, the criteria of relevance, novelty, and the possibility of further citation for comparison with the data obtained were taken into account. Accordingly, the study is based on methods such as analysis, synthesis, comparative legal method, generalization method, etc.

3 RESULTS AND DISCUSSION

3.1 Biotechnology and forensic applications

It is concluded that the scope and features of diverse biotechnological tools show that their competent use during crime scene inspection can make a decisive contribution to establishing the truth in criminal cases.

The concept of "biotechnology" appeared in our language relatively recently. As E.A. Myshak points out , this term, proposed back in 1917, meant types of work in which certain products are produced from raw materials using living organisms. Despite the capacious reflection of the essence of technology, this understanding did not take hold, and therefore for a long time the term "biotechnology" was used in two ways: some used it in connection with the fermentation process, others implied a person and his practical activity with the aim of optimizing tools, conditions and the process of labor. Until 1971, the term "biotechnology" was used mainly in the food industry and agriculture. At the moment, there are many interpretations of the concept, but in general they all boil down to one thing: in the traditional sense, biotechnology is an interdisciplinary field that arose at the junction of biological, chemical and technical sciences; this is the use of living organisms and biological processes in industrial production (Myshak 2018, p. 19).

Thus, biotechnology is an integration of natural and technical sciences, providing opportunities to use living organisms and biological processes for the production and processing of various valuable substances and products. Today, biotechnology is one of the most priority areas of scientific and technical progress, being a striking example of "high technology".

Since the appearance of the term "biotechnology" and the first developments in the field of microbiology, biochemistry, and molecular genetics, questions have arisen about the use of such achievements in investigative practice, since the use of biological properties of organisms has made it possible to expand the possibilities of searching for and identifying traces of blood, saliva, sperm, sweat, hair, and other samples of biological origin.

Classic examples of the application of biotechnology in forensic science are DNA typing methods, which became widespread in the late 20th and early 21st centuries. Various options for analyzing short tandem repeats (DNA analysis), mitochondrial DNA, polymorphic loci, as well as modern highly sensitive next-generation sequencing (NGS) methods have made it possible to identify individuals at an extremely high level of accuracy. Similar technologies are also used when working with samples of difficult-to-identify remains or heavily destroyed, partially degraded biological traces. As part of the examination of the crime scene, biotechnological approaches help not only in the subsequent identification of defendants in a criminal case, but also in determining the mechanisms of trace formation , time intervals of events, and other factors important for establishing the truth (Grachenko 2023, p. 103).

Along with DNA analysis methods, biochemical and immunological tests are of great importance, allowing screening of specific biological fluids. Portable devices are emerging that are capable of conducting express analysis of detected spots in the field, determining the species and basic characteristics of the blood. Although such devices have existed for several decades, their improvement directly depends on the development of biotechnology, aimed at increasing the selectivity, specificity and sensitivity of reagents.

The most relevant areas in which the achievements of biotechnology are reflected in the WMD can be designated as molecular genetic methods, biochemical rapid tests, bioengineering solutions for the detection and visualization of biological traces, as well

as technologies related to remote or automated analysis of samples. Molecular genetic methods include, first of all, high-precision DNA expertise (Kruchinina 2022, p. 32).

The evolution of biochemical express tests provides the possibility of more reliable detection of small and partially invisible stains of blood, saliva, sperm and other liquids with minimal destruction of the trace itself. For example, as G. Zhumagulova , T. Zhakupova , V. Osipov and G.V. Zhakenova in the daily practice of the Republic of Kazakhstan for the detection of sperm for ten years (since 2004) has been widely used immunochromatographic express test for semi-quantitative detection of prostate specific antigen, presented by a German company (2022). At the same time, many countries are working on the creation of illuminating lamps with an adjustable range of waves and a system of light filters to detect traces of biological origin without violating their physical and chemical properties. Already at the scene of the crime, an investigator or forensic expert with the help of such technologies is able to detect biological material and then send it to the laboratory, eliminating the risk of losing the trace. Also, such illuminators allow working in conditions of poor visibility, which is often encountered at the scene of the crime.

Bioengineering solutions offer a whole range of tools and methods. These can be various wearable devices for collecting samples, capable of immediately preserving DNA, preventing its decomposition. A number of laboratories in the USA and Europe are developing microchips that allow combining the stages of DNA extraction, its amplification and primary analysis in one closed block. The advantage of such technologies is that the test is carried out in the format of “one sample = one reaction volume of the biochip”, i.e. the sample does not need to be divided into several parts and analyzed separately. (Rubtsova 2022, p. 13).

3.2 New technologies and international practices

Biotechnology in a broad sense includes not only DNA or protein analysis methods. In recent years, research related to metagenomics has been gaining momentum - the study of the genetic material of a set of microorganisms living in a sample (for example, on a crime weapon or on the surface of the victim's body). The method allows one to determine the species diversity of microflora and identify specific patterns that are

formed under certain conditions, including at the crime scene. With the help of this information, it is sometimes possible to reconstruct the age of an event or contact interactions between objects, people, animals.

For example, promising areas include the analysis of "epigenetic markers," which make it possible to determine the approximate age of a person who has undergone biological testing, as well as to identify factors associated with his or her lifestyle (smoking, taking certain substances, the presence of chronic diseases).

Another particular area of biotechnology development in forensic science is the CRISPR/ Cas technology, which can be used in forensic genetics for highly sensitive detection of specific genetic variations. Although CRISPR/ Cas initially acted as a genome editing method, its side applications in diagnostics allow the development of highly accurate systems for recognizing the necessary DNA or RNA fragments. However, this area is still in the research stage and has not become a routine practice in forensic science (Wang *et al*. 2013).

The practice of using biotechnology in crime scene investigations varies significantly across countries, depending on the level of scientific and technological development, financial resources, and the legal framework.

In the United States, there is a diversified system of forensic laboratories in law enforcement agencies, including the FBI, which widely use DNA analysis with CODIS panels. The development of DNA analysis technologies and the introduction of DNA profiling to establish identity and kinship reached a high level back in the 1990s. Today, American specialists increasingly use portable PCR analyzers at the scene of a crime for a quick preliminary assessment of samples. At the same time, in US practice, as noted by the National Institute of Justice, there is a high need to train field investigators in the correct methods of collecting and labeling samples, since the intricacies of biotechnological procedures require special care (Wang *et al*. 2013).

In the countries of the European Union, in particular in Great Britain, Germany, France, there is an active introduction of new methods of molecular visualization of traces (use of broad-spectrum lamps and special fluorescent dyes) (Yablokov and Aleksandrov 2025, p. 49).

Russia is also actively implementing biotechnological approaches. However, as researchers note, some regional departments lack specialists who know how to properly

handle biological traces at the scene of a crime. At the same time, leading expert institutions are implementing modern DNA technologies, working to improve the range of immunochemical tests and introduce automated stations for sample preparation. The difficulty is that at the local level, especially in small towns, an investigator cannot always quickly contact a specialist and competently apply certain technical and forensic tools (Yablokov and Aleksandrov 2025, p. 172). Taking into account foreign experience, specialists in Russia point to the need to create a Unified State Register of Forensic Specialists (or a similar information resource) so that investigators know who to turn to for help (Aritkulova 2020, p. 129.

3.3 Challenges, risks, and legal-ethical issues

Biotechnology, being a highly effective tool in the hands of an expert, at the same time assumes high risks in case of careless handling of evidence and failure to comply with methodological requirements. One of the main problems is the risk of loss or damage of biological traces. Dried blood, for example, easily separates from objects, and traces can be lost. At the same time, today there is a shortage of modern equipment that would help detect traces (for example, blood) without damaging their physical and chemical properties, and also allow working in low light conditions.

Another set of problems is related to the fact that investigators do not always have sufficient specialized knowledge in the field of biotechnology and the specifics of biological traces. As noted in studies, while in large cities there is the possibility of quickly calling a competent specialist, in remote areas such a resource may be absent or its search is very difficult. As a result, traces seized without the necessary caution and correct methodology lose value for further examination or are unsuitable for DNA analysis.

The issue of the sequence of actions during the inspection of the crime scene also remains relevant. The same object with biological traces may be subject to different types of research - genetic, dactyloscopic, traceological and others. The wrong sequence of actions may lead to the destruction or contamination of the trace. As a result, a situation arises when it is subsequently impossible to reconstruct the picture of the incident based on faded or partially erased blood stains, hair that has lost its primary characteristics or

other materials of biological origin. However, as V.N. Karagodin and E.V. Morozova point out, studies have shown that technical and forensic means for detecting micro-objects, ultraviolet, infrared illuminators, etc. are rarely used during crime scene inspections (Karagodin and Smarktin 2025, p.8).

In addition, in order to overcome the “information blockade” of investigators, scientists propose to form unified registers of forensic experts, accessible to law enforcement agencies. Such a practice exists, for example, in Germany, where there is a database of experts certified by the relevant organizations, and to whom the investigator can turn for advice or with a request to go to the scene of the incident. As a result, the efficiency of searching for and seizing biological traces increases (Rubstova 2022, p.13).

Thus , despite the broad opportunities that biotechnology opens up, its use in forensics also gives rise to a number of serious legal and ethical risks. Firstly, concerns are related to the possibility of abuse and falsification of DNA analysis results. The high sensitivity of the methods allows detecting even minimal admixtures of genetic material, which, on the one hand, is useful for investigation, and on the other hand, increases the risk of intentional or unintentional contamination, as well as "planting" of someone else's material. If strict rules for recording and protecting traces are not observed during the WMD, the result of the DNA examination may be questioned in court.

Secondly, technological difficulties are associated with the need to use expensive equipment and consumables, as well as with the costs of training personnel. With irrational use of resources or in the absence of proper control over the procedures carried out, the risk of incorrect interpretation of data increases.

Thirdly, the issue of ethical and legal responsibility is related to the privacy of genetic information, because DNA contains not only information about a person, but also indirect data about his relatives. Regulating access to genetic databases and limiting the circle of people who have access to them is a separate task for legislative bodies.

Fourthly, the issue of interstate exchange of DNA data is becoming relevant in cases where a crime affects several countries. International organizations such as Interpol are developing agreements and standards for interaction between forensic services of different countries, but the level of integration varies from country to country. At the same time, differences in national legislation regarding the limits and conditions for the use of

genetic data remain, which can lead to conflict situations or complicated information exchange procedures.

Finally, we should not forget about the moral side of the issue when technologies allow, for example, to determine racial and ethnic characteristics, physical features, predisposition to diseases, age, etc. The possibility of extended DNA profiling gives rise to discussions in the scientific community about the permissible limits of interference in private life. This is indicated, for example, by J. Santalo and M. Berdasco , according to whom epigenetics is of great interest both at the ethical and social levels. Some experts believe that such research is justified for solving particularly serious crimes (for example, a series of murders), while others fear that such a practice could lead to stigmatization of certain groups of the population (Santaló and Berdasco 2022).

The issues of risks and responsibilities of using biotechnology are also particularly important in connection with the need to respect the rights of citizens who are innocent of committing crimes. It is unacceptable to expand genetic databases without appropriate legal protection. A mechanism is needed to provide for the deletion of profiles of those persons against whom criminal prosecution has been terminated and a clear definition of the range of cases in which forced DNA extraction is permitted. A possible solution is to establish an independent body to regulate the use of biotechnology in forensic science, which would develop standards and monitor compliance with ethical norms, as well as coordinate cooperation between expert institutions. In some countries, this function is partially performed by professional associations of criminologists and forensic doctors, but for full effectiveness, a state representative is needed.

It should also be noted that in WMD, the time factor is of paramount importance. The faster the traces are removed, the greater the chance of preserving them in a form that will provide maximum information during laboratory analysis. According to research, a delay of hours or days can lead to irreversible processes of DNA degradation, coagulated proteins, bacterial decomposition, and moisture loss, which will complicate or make the study impossible. To reduce the time, it is recommended to involve a specialist in biological traces (or have specially trained investigators) at the earliest possible stage. However, as noted above, regional links often do not have systematized data on available specialists. Therefore, the organization of a central register of forensic experts and mandatory informing of investigators about its availability is considered a priority.

When working with hair or other micro-traces, one must also take into account the so-called "risk of cross-contamination". If tweezers are used to collect hair and then another sample is collected with them without proper cleaning, then biomaterials from different objects may be mixed in the subsequent laboratory analysis. Such an error can distort the entire investigation. International standards recommend using disposable instruments, and if they are not available, disinfecting tweezers or scissors before each new object. The optimal solution in developed laboratories is special replaceable attachments or disposable adhesive strips.

The legal aspect of the application of biotechnological methods in forensic science covers both procedural legislation (admissibility of evidence, the procedure for collecting it) and the areas of personal data protection, ethics, and human rights. Given the growing role of genetic technologies, it is advisable for each state to have a separate regulatory framework establishing the limits and procedure for conducting genetic testing in criminal proceedings, as well as measures of liability for violating it. In the future, we should expect further improvement of express approaches that allow not only a primary blood test to be carried out directly at the scene of the incident, but also a partial DNA analysis, which has already been partially implemented in a number of foreign developments, but still remains expensive and requires a qualified user. If such portable complexes become more accessible, the investigation procedure will be significantly accelerated, especially in cases where every hour counts or when there is a large array of victims and evidence (mass crimes, terrorist attacks, natural disasters).

Another important perspective is the expansion of the use of RNA analysis methods, which allow them not only to identify a person, but also to determine the type of biological tissue (blood, saliva, sperm, tears) with high accuracy. Such methods are based on the fact that different types of tissue have characteristic gene expression "signatures". Considering that classical chemical tests do not always work with highly degraded samples, RNA analysis methods can give forensic experts an additional tool for reconstructing the picture of the incident.

4 CONCLUSION

Thus, as the conducted research has shown, biotechnology plays an increasingly important role in the examination of the crime scene, opening up wide opportunities for the detection, recording and analysis of traces of biological origin. Their use helps to increase the accuracy of establishing the factual circumstances of the case, including identification of the person, determination of the mechanism of trace formation and time parameters of the incident.

Among the most pressing issues requiring resolution in the near future are the problem of technical and personnel support for regional units of investigative bodies, the difficulty of preserving the integrity and evidentiary value of biological traces at the scene of the incident, and the need to harmonize national legislation with international standards. Elimination of these gaps will allow the effective use of the full potential of biotechnology in conducting WMD.

The scope and features of diverse biotechnological tools show that their competent application in WMD can make a decisive contribution to establishing the truth in criminal cases. It is important to remember that success depends not only on technology, but also on the human factor - the competence of specialists, the discipline of storing traces and following methodological standards. Taking into account the experience of foreign countries, it becomes obvious that complexity, interdepartmental cooperation and a unified training system are key factors determining the effectiveness of using biotechnology in forensic science.

DECLARATION OF COMPETING INTEREST

The authors declare that there is no competing interests to any authors.

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Authors' Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

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