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THE ROLE AND IMPORTANCE OF MODERN IT TECHNOLOGIES AND ARTIFICIAL INTELLIGENCE IN THE PRODUCTION OF ANTIBIOTIC PHARMACEUTICALS

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Abstract

This article highlights the role of modern information technologies and artificial intelligence in the production of antibiotic pharmaceuticals. In recent years, the integration of computer technologies, bioinformatics, and artificial intelligence in the pharmaceutical industry has significantly accelerated and simplified antibiotic development processes. Artificial intelligence systems provide wide opportunities in identifying bacterial resistance mechanisms and predicting the structure of potential active compounds, thereby enhancing laboratory research efficiency.

The article emphasizes the importance of IT technologies in improving the effectiveness of antibiotic production, reducing costs, and creating new pharmaceutical agents. Additionally, it discusses the application of modern digital tools in the fight against antibiotic resistance. The study also reviews innovative developments based on artificial intelligence that contribute to advances in antibiotic discovery and development.

Introduction

An antibiotic is a pharmaceutical agent used to treat diseases caused by bacteria, fungi, or other microorganisms. Antibiotics either destroy bacteria or inhibit their reproduction. Antibiotic therapy began after the discovery of penicillin by the Scottish scientist Alexander Fleming in 1928. This discovery is considered one of the greatest achievements in human history, saving millions of lives.

Antibiotics are classified into three main groups according to their mechanisms of action.

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The first group disrupts the bacterial cell wall, and includes agents such as *penicillins* and *cephalosporins*.
The second group inhibits protein synthesis, represented by drugs such as *tetracyclines* and *erythromycins*.
The third group interferes with DNA or RNA synthesis, for example, *rifampicin*.
It is important to note that antibiotics are **not effective** against viral infections. Therefore, using antibiotics to treat influenza, the common cold, or COVID-19 is both harmful and inappropriate.

Main Part

Modern IT technologies and artificial intelligence (AI) have significantly transformed the process of antibiotic production. Antibiotics play a crucial role in maintaining human health, and their importance in combating bacterial infections remains undeniable. In this context, contemporary technologies such as information technology and artificial intelligence facilitate the development and enhancement of antibiotic manufacturing processes.

IT systems and AI contribute to increasing efficiency, improving accuracy, and accelerating research aimed at discovering new, broad-spectrum antibiotics. These technologies enable pharmaceutical industries to optimize laboratory operations, identify potential chemical compounds more rapidly, analyze bacterial resistance mechanisms, and predict molecular structures with therapeutic potential. Consequently, modern technological tools not only simplify antibiotic production but also play a pivotal role in ensuring the development of next-generation antimicrobial agents.

Role of IT Technologies

- **Data storage and analysis:**
- With the help of information technologies, large volumes of data (such as clinical, molecular, and genomic data) can be stored and subsequently analyzed. This significantly enhances the identification of new antibiotics and enables a deeper understanding of their mechanisms of action.
- **Process automation:**
- Automation of manufacturing processes increases the quality and efficiency of antibiotic production. IT technologies are employed to digitalize logistics and monitoring operations. This approach minimizes errors, accelerates production cycles, and ensures process stability.

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• **Quality control:**

• Computer vision systems and advanced sensors are used to continuously monitor the quality of antibiotic products. This ensures that manufactured medicines comply with established pharmaceutical standards and regulatory requirements.

• **Research and development:**

• IT technologies and AI-based algorithms analyze large datasets to identify new antibiotic molecules and predict their potential therapeutic effectiveness. As a result, the process of developing new antibiotics becomes faster, more accurate, and more efficient.

1. Artificial Intelligence (AI)

Artificial intelligence (AI) is a technology that enables computer systems to learn, analyze information, and make decisions in a manner similar to humans.

2. The Role of Artificial Intelligence in Antibiotic Production

• Artificial intelligence (AI) analyzes the structure of thousands of chemical compounds and predicts their potential antibacterial effects in advance.

• Through this approach, the process of discovering new and highly effective antibiotics is significantly accelerated — instead of taking years, it can be accomplished within months or even weeks.

Notably, in 2025, artificial intelligence-based molecular screening platforms successfully identified two promising antibiotic candidates, NG1 and DN1, highlighting AI's pivotal role in expanding the modern antibiotic pipeline and combating antimicrobial resistance.

3. Acceleration of Antibiotic Production through Artificial Intelligence

• Artificial intelligence (AI) can significantly accelerate the antibiotic development and production process by employing various advanced computational methods. Traditional approaches often require extensive time and substantial financial and laboratory resources; however, AI-driven techniques have made it possible to considerably speed up these stages.

• **Prediction of antibiotic drug candidates:** AI technologies analyze molecular structures and simulate their potential interactions with pathogenic microorganisms. This capability enables researchers to identify promising antibiotic compounds and prioritize them for further experimental and clinical testing.

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• **Enhancement of existing antibiotics:** AI systems examine the structural features of currently available antibiotics and propose modifications aimed at improving their therapeutic efficacy or minimizing undesirable side effects. Through such optimization, AI contributes not only to the discovery of new antibiotics, but also to the refinement of existing pharmaceutical agents.

4. Methods of Antibiotic Design and Optimization Using Artificial Intelligence

• Artificial intelligence facilitates the development of novel antibiotics through molecular modeling, enabling the simulation of chemical interactions and biological activity prior to laboratory synthesis.

• AI-driven algorithms are capable of predicting key pharmacological properties of antibiotic candidates, including antimicrobial potency, spectrum of activity, stability, and resistance-avoidance potential.

• As a result, it becomes unnecessary to conduct laboratory experiments on every individual compound, which substantially reduces research time, operational costs, and resource consumption in the drug-development pipeline.

5. Regulatory and Operational Principles of Using Artificial Intelligence in Antibiotic Development

• Artificial intelligence is increasingly applied as an efficient approach in antibiotic development, particularly in process automation, quality monitoring, and biosafety control. However, the deployment of AI technologies in pharmaceutical production must comply with specific regulatory frameworks and professional standards.

• AI systems operate accurately only when trained on complete, verified, and high-quality datasets. Therefore, clinical, laboratory, and genomic information used for training must be thoroughly validated.

• Any form of data inaccuracy may result in computational errors and inaccurate predictive outcomes; thus, rigorous data preprocessing, filtering, and optimization remain essential.

• AI-based platforms in antibiotic development typically handle extremely large biomedical datasets. Consequently, these data must be protected from cyber-attacks, industrial espionage, and unauthorized access.

• To ensure data integrity and confidentiality, robust encryption mechanisms, secure network infrastructure, and strict cybersecurity protocols must be maintained throughout the development cycle.

6. The Role of Artificial Intelligence in Environmental and Biosafety Regulations

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• The use of artificial intelligence in antibiotic development and testing significantly reduces potential environmental harm by optimizing laboratory processes and minimizing biological risks.

• AI systems monitor the handling of microorganisms and experimental waste, ensuring proper sterilization and safe disposal through automated biosafety protocols.

• Overall, artificial intelligence plays a critical role in enforcing ecological and biosafety standards, strengthening bio-containment measures, and preventing accidental contamination.

• In environmental protection, AI-powered analytical tools help forecast pollution levels, identify ecological risks, and contribute to climate monitoring and mitigation strategies.

• AI systems are essential for detecting hazardous situations, supervising technological operations, and preventing emergency scenarios, thereby enhancing industrial safety and sustainable biomedical production.

7. Modern IT Technologies in Antibiotic Production

• Modern bioinformatics platforms enable the analysis of microbial DNA and RNA, facilitating the identification of genes with potential antibiotic properties and accelerating the discovery of novel bioactive compounds.

• Cloud-based technologies support the storage, management, and large-scale processing of massive biological datasets, providing efficient computational resources for advanced genomic and proteomic research in antibiotic development.

8. Traditional Methods in Antibiotic Production

Traditional approaches to antibiotic manufacturing involve obtaining antibiotic compounds from natural microorganisms (e.g., fungi or bacteria) by cultivating them under controlled conditions. The principal methods are detailed below:

• **Fermentation (biotechnological) method.**

• This is the most fundamental and classical approach to antibiotic production, whereby selected microbial strains are cultured in optimized media to biosynthesize target antibiotic metabolites at scale.

• **Chemical modification (semisynthetic) method.**

• In this approach, naturally derived antibiotic scaffolds are subjected to targeted chemical transformations to improve their potency, spectrum of activity, pharmacokinetics, or safety profile, yielding semisynthetic antibiotics.

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For example, **Penicillin-G** is obtained from natural microbial sources, and then chemical modification is applied to produce more stable derivatives such as **amoxicillin** and **ampicillin**. This method broadens the antimicrobial spectrum of antibiotics and contributes to reducing bacterial resistance.

- **Extraction method.**
- In certain cases, antibiotics are directly isolated from the culture broth of microorganisms using organic solvents (such as ethyl acetate or chloroform). After extraction, the solvent is evaporated and the active compound is obtained in crystalline form.
- **Biological control and standardization method.**
- During antibiotic production, parameters such as antimicrobial activity, dosage accuracy, purity, and stability are continuously monitored. For instance, test microorganisms like *E. coli* or *Staphylococcus aureus* are used to assess antibiotic efficacy and ensure compliance with pharmaceutical standards.

Traditional Methods in Antibiotic Production

Traditional (also known as classical or early-stage biotechnological) methods of antibiotic production are based on obtaining antibiotics naturally from microorganisms. The main stages of this process are outlined below:

1. Selection of Microorganisms

- Microorganisms capable of producing antibiotics are isolated from natural sources such as soil, water, plants, and animal organisms.
- Most commonly used antibiotic-producing organisms include actinomycetes (e.g., *Streptomyces*), *Bacillus* species, and fungi such as *Penicillium*.
- The isolated strains are cultured in specific nutrient media, after which their antibiotic-producing ability is tested and evaluated.

2. Fermentation (Biotechnological Cultivation)

- The selected microorganisms are cultivated in fermentation units (bioreactors) in nutrient media.
- Essential cultivation conditions include:
- **Temperature:** approximately 25–30°C
- **pH:** neutral or slightly acidic
- **Aeration:** sufficient oxygen supply

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• **Agitation:** to maintain uniform distribution of nutrients and cells

• During this process, microorganisms produce antibiotics as **secondary metabolites**.

3. Antibiotic Extraction

• After fermentation, the antibiotic is isolated from the broth through **filtration, precipitation, or extraction** techniques.

• The **active ingredient concentration, stability,** and **sterility** of the antibiotic are examined.

• Subsequently, it is processed into **pharmaceutical dosage forms** such as tablets, solutions, ointments, and others.

Additional Information

In traditional methods, discovering new antibiotics requires extensive investigation of natural sources and optimization of fermentation conditions. Today, these classical techniques are complemented by **genetic engineering** and **synthetic biotechnology** approaches.

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1. Screening and Selection of Microorganisms

Sources:

• Soil — the richest source due to the abundance of *Actinomycetes*,

• Water bodies and plant residues — also considered potential reservoirs.

Process:

1. A soil sample is collected and suspended in water.
2. The suspension is plated on **selective nutrient media** (agar plates).
3. Grown colonies are examined under a microscope and selected based on their **morphological characteristics and pigmentation.**

Advantages of Artificial Intelligence in Antibiotic Development

• **Acceleration of Discovery** — Traditional methods for identifying new antibiotic molecules may require several years; however, AI-driven approaches significantly accelerate this process. For instance, in one study, analysis of microbiome datasets enabled the identification of nearly **one million potential antibiotic candidates.**

• **Expansion of Chemical Space** — AI systems can propose novel molecular structures that might not be predicted by human researchers, thus **expanding the**

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accessible chemical space and offering innovative opportunities for drug discovery.

• **Process Optimization** — AI enables **real-time monitoring and optimization** of fermentation processes, improving yield and efficiency. For example, the combination of **NIR spectroscopy, Raman spectroscopy, and machine learning** increased fermentation productivity by up to **30%.**

• **Prediction and Prevention of Antibiotic Resistance** — AI algorithms can analyze bacterial behavior and **predict resistance mechanisms** before they emerge, assisting in the development of proactive strategies to mitigate or prevent antimicrobial resistance.

Role of Artificial Intelligence

• **Data Analysis:**

• Artificial intelligence analyzes genomic, metagenomic, and proteomic datasets to predict which microorganisms possess **antibiotic biosynthetic gene clusters.**

• **Machine Learning:**

• Advanced machine-learning models are used to detect **biosynthetic gene clusters (BGCs)** within microbial genomes, enabling automated identification of potential antibiotic-producing organisms.

• **Outcome:**

• As a result, natural antibiotic-producing microorganisms are discovered significantly faster.

• For example, in **2023**, a DeepMind-MIT collaborative AI model analyzed **over 700 million genomic records** and identified **more than 50 potential antibiotic-producing bacterial strains**.

Conclusion

Artificial intelligence (AI) and modern information technologies significantly enhance both the **discovery** and **production efficiency** of antibiotics. AI-based drug-discovery models (such as Halicin and subsequent studies) represent a major breakthrough in the field. However, practical implementation requires **strict regulatory coordination**, **robust experimental validation**, and **comprehensive safety assurance** prior to clinical adoption.

Traditional antibiotic production methods:

• rely on microorganisms as the primary source,

• are based on fermentation processes,

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• include purification, chemical modification, and multi-stage quality control.

When these classical biotechnological approaches are combined with **modern biotechnology and genetic engineering**, they open the way for the development of a **new generation of antibiotics** capable of addressing emerging microbial resistance challenges.

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