

ANTIBIOTICS AND ANTIBIOTIC RESISTANCE

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Abstract

Antibiotics are among the most important therapeutic tools of modern medicine, responsible for a dramatic reduction in mortality from bacterial infections since the mid-twentieth century. However, the widespread and sometimes irrational use of these drugs in clinical practice, veterinary medicine, and agriculture has driven the emergence and rapid spread of antibiotic-resistant bacteria. This article reviews the classification and mechanisms of action of antibiotics, the biological mechanisms by which bacteria acquire resistance, the main factors contributing to the global spread of resistant strains, and the strategies currently being pursued to slow this process. Particular attention is given to the concept of antimicrobial stewardship and to the role of international cooperation in addressing what the World Health Organization has described as one of the greatest threats to global health.

Introduction

The discovery of penicillin by Alexander Fleming in 1928 and its subsequent development into a clinically usable drug in the early 1940s marked the beginning of the antibiotic era. Since then, dozens of antibiotic classes have been introduced into clinical practice, transforming once-fatal infections such as pneumonia, tuberculosis, and septicemia into treatable conditions. Antibiotics have also made possible many achievements of modern medicine that depend on effective infection control, including organ transplantation, cancer chemotherapy, and complex surgery.

At the same time, bacteria are highly adaptable organisms capable of evolving resistance mechanisms in response to selective pressure. Every exposure of a bacterial population to an antibiotic creates conditions favoring the survival and proliferation of resistant variants. Over the past several decades, the pace of antibiotic discovery has slowed considerably, while the prevalence of resistant pathogens has increased steadily, creating a widening gap between therapeutic need and available treatment options.

2. Classification and Mechanisms of Action of Antibiotics

Antibiotics are generally classified according to their chemical structure and their mechanism of action. Beta-lactam antibiotics, including penicillins, cephalosporins, and carbapenems, act by inhibiting the synthesis of the bacterial cell wall through binding to penicillin-binding proteins, ultimately causing cell lysis. Aminoglycosides and macrolides interfere with bacterial protein synthesis by binding to different subunits of the ribosome. Fluoroquinolones inhibit bacterial DNA gyrase and topoisomerase IV, enzymes essential for DNA replication. Sulfonamides and trimethoprim disrupt folic acid synthesis, a pathway required for nucleic acid production that is absent in human cells but present in bacteria.





Antibiotics may also be classified as bactericidal, meaning they kill bacteria directly, or bacteriostatic, meaning they inhibit bacterial growth and rely on the host immune system to eliminate the pathogen. The choice of antibiotic in clinical practice depends on the suspected or confirmed causative organism, the site of infection, the pharmacokinetic properties of the drug, and patient-specific factors such as allergy history, renal function, and pregnancy status.

3. Mechanisms of Antibiotic Resistance

Bacterial resistance to antibiotics arises through several interconnected mechanisms. Enzymatic inactivation is one of the most common, exemplified by beta-lactamase enzymes that hydrolyze the beta-lactam ring of penicillins and cephalosporins, rendering them ineffective. Target modification is another major mechanism, in which mutations alter the structure of the molecule that the antibiotic normally binds to, reducing drug affinity while preserving the target's biological function, as seen in methicillin-resistant *Staphylococcus aureus* (MRSA).

Efflux pumps represent a further mechanism, actively transporting antibiotic molecules out of the bacterial cell before they can reach an effective intracellular concentration. Reduced membrane permeability, particularly in gram-negative bacteria, limits the entry of antibiotics into the cell. Finally, bacteria are able to acquire resistance genes horizontally through plasmids, transposons, and bacteriophages, allowing resistance traits to spread rapidly not only within a single species but across different bacterial genera.

4. Factors Driving the Spread of Resistance

The overuse and misuse of antibiotics in human medicine is a central driver of resistance. This includes prescribing antibiotics for viral infections against which they have no effect, failure to complete prescribed treatment courses, and the availability of antibiotics without medical prescription in many countries. Excessive use of antibiotics in livestock farming, often for growth promotion rather than treatment of disease, is another significant contributor, as resistant bacteria can transfer from animals to humans through the food chain and environmental contamination.

Inadequate infection control practices in hospitals and other healthcare settings facilitate the transmission of resistant organisms between patients. Poor sanitation and limited access to clean water in some regions further promote the spread of resistant bacteria within communities. Globalization and international travel accelerate the dissemination of resistant strains across borders, meaning that a resistance problem originating in one country can quickly become a global concern.

5. Strategies to Combat Antibiotic Resistance

Antimicrobial stewardship programs, which promote the appropriate selection, dosing, and duration of antibiotic therapy, have proven effective in reducing unnecessary antibiotic use in hospital settings. Strengthening diagnostic capacity, including rapid point-of-care testing to distinguish bacterial from viral infections, allows clinicians to avoid unnecessary prescriptions. Public education campaigns aimed at both patients and prescribers help correct misconceptions about antibiotic use.

At the policy level, many countries have introduced regulations restricting the sale of antibiotics without prescription and limiting their use in agriculture. International organizations, including the World Health Organization, have developed global action plans to coordinate surveillance of resistant





pathogens and to encourage research into new antimicrobial agents. Investment in the development of novel antibiotics, alternative therapies such as bacteriophage therapy, and vaccines that reduce the incidence of bacterial infections are also regarded as essential components of a long-term response.

6. Conclusion

Antibiotic resistance is a complex, multifactorial problem that threatens to undermine decades of progress in the treatment of infectious disease. Addressing it requires coordinated action across human medicine, veterinary practice, agriculture, and public policy, guided by the principle that antibiotics are a shared and finite resource. Responsible use of existing antibiotics, combined with sustained investment in new therapeutic options and robust surveillance systems, offers the most realistic path toward preserving the effectiveness of these essential drugs for future generations.

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