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2025 Volume 6, Issue 3
Cell Biology Research
ISSN: 2529-7627 (Online)

How Should We Deal with the Failure of Antibiotics Draft I

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Abstract: The discovery and development of antibiotics have revolutionized modern medicine, saving millions of lives and reshaping global public health. However, antibiotic resistance has emerged as a formidable challenge, driven by clinical misuse, agricultural overuse, and environmental neglect. This review outlines the historical trajectory of antibiotics, from Fleming's discovery of penicillin to the current AI-assisted discovery approaches. We classify commonly used antibiotics, summarize their mechanisms of action, and discuss the societal and medical significance of antibiotics. Moreover, we analyze the underlying causes of the growing antibiotic resistance crisis and propose targeted strategies—including regulation, education, and technological innovation—to safeguard the efficacy of antibiotics in the future.

Keywords: Antibiotic resistance; Antimicrobial discovery; Public health; Misuse of antibiotics; Artificial intelligence; Drug development

Online publication: September 26, 2025

1. Introduction

The discovery of antibiotics marked one of the most significant medical advances of the 20th century. In 1928, Alexander Fleming observed the inhibitory effects of a mold (Penicillium) on surrounding bacteria, leading to the discovery of penicillin. This breakthrough revolutionized the treatment of infectious diseases, particularly during World War II. Since then, humans have embarked on a journey to explore, synthesize, and optimize antimicrobial agents. Excluding accidental ancient uses, the history of antibiotic discovery can be categorized into four major eras[1].

The Golden Age of Antibiotics (1920s–1950s) began with Fleming's discovery and was followed by systematic isolation of soil-derived antibiotics by Waksman and others, including streptomycin. The Synthetic Modification Period (1950s–1970s) introduced structural refinements through medicinal chemistry to enhance efficacy and reduce toxicity. The Discovery Drought (1980s–2000s) saw reduced innovation as pharmaceutical companies redirected investments to chronic diseases (Aminov, 2010). The Modern Era (2000s–present) integrates genome mining, CRISPR, AI-assisted drug design, and phage therapy to combat antibiotic-resistant pathogens (Lewis, 2020)[2].

Table 1. Classification of common antibiotics

Catagory[3]	Examples	Mechanism[4]	Common Uses for treatment[5]
B-Lactams (4-membered ring)	Penicillin, Amoxicillin	Destroy bacteria, by breaking cell walls	Strep throat ear infections
Macrolides (large rings)	Erythromycin, Azithromycin	Destroy bacterial ribosomes to stop the bacteria from producing proteins	Pneumonia, whooping cough
Aminoglycosides (sugar groups)	Streptomycin, Gentamicin	Sabotage genetic code translation	Tuberculosis, severe gut infections
Tetracyclines (4 benzene rings)	Doxycycline	block proteins + Block bacteria from gaining energy	Acne, Lyme disease
Quinolones (synthetic)	Ciprofloxacin	Destroy bacterial DNA during replication	UTIs, food poisoning
B-Lactams (4-membered ring)	Penicillin, Amoxicillin	Destroy bacteria, by breaking cell walls	Strep throat ear infections
Macrolides (large rings)	Erythromycin, Azithromycin	Destroy bacterial ribosomes to stop the bacteria from producing proteins	Pneumonia, whooping cough

2.1. The Significance of Antibiotics

Antibiotics have reduced bacterial infection–related mortality by over 80%, contributing to an increase in global life expectancy by approximately 23 years[6]. They are essential for treating conditions such as sepsis and post-surgical infections[7]. Additionally, antibiotics prevent fatal neonatal infections, although overuse can disrupt gut microbiota and immune development[6]. In agriculture, antibiotics reduce animal disease and enhance productivity by up to 20%[8]. Furthermore, they are integral to the safety of consumer products, such as contact lens disinfectants[9].

2.2. Mechanisms of Bacterial Resistance

Bacteria resist antibiotics through several mechanisms:

(1) Cell wall thickening[10];

(2) Production of β-lactamases to degrade antibiotics[11];

(3) Ribosomal modification, rendering macrolides ineffective[12];

(4) Horizontal gene transfer via plasmids and bacteriophages[13].

2.3. Purpose of the Research

Despite modern technologies, the effective antibiotic arsenal is shrinking due to overuse and bacterial adaptation. This study investigates the multifactorial causes of antibiotic efficacy decline and proposes actionable strategies to prolong antibiotic utility.

2.4. Causes and Solutions to the Current Antibiotic Crisis

3. Agricultural Misuse

The overuse of antibiotics in livestock fosters resistant bacteria that may transfer to humans. Zhang et al demonstrated that industrial farming practices lead to unintentional antibiotic ingestion, gut microbiome imbalance, and colonization by resistant strains[14]. To mitigate this:

(1) Implement vertically integrated poultry operations with disease control;

(2) Substitute antibiotics with probiotics, organic acids, enzymes;
(3) Develop effective vaccines;
(4) Enforce regulations on antibiotic residues and restrict contaminated meat sales.

4. Clinical Misuse

Medical misuse, including incorrect prescriptions and premature discontinuation, exacerbates resistance. Alrasheedy et al[15] reported high rates of prescription errors, often involving unnecessary antibiotics. Solutions include:
(1) Involving pharmacists in treatment plans;
(2) Restricting over-the-counter antibiotic sales;
(3) Monitoring hospital antibiotic use;
(4) Isolating patients with resistant infections to prevent spread.

5. Lack of Public Awareness

Public understanding of antibiotic resistance is limited. Narmeen Mallah found that misuse correlates more with accessibility than education level[16]. Additionally, Rossi highlighted that dairy products harbor Pseudomonas spp., which carry resistance genes[17] . Addressing this requires:
(1) Mandatory public education on antibiotic use;
(2) Legal accountability for food and medical product manufacturers.

6. Future Directions: AI-Assisted Discovery

Antibiotic R&D is costly and high-risk, deterring investment. Zavaleta-Monestel proposed AI-assisted platforms to identify effective compounds and simulate clinical trials[18]. These technologies promise to reduce costs and timelines, thus revitalizing antibiotic discovery.

7. Discussion

Antibiotic resistance is a multifaceted issue, deeply entangled with human behavior, economic interests, and global health governance. Agricultural and clinical misuse are widely recognized contributors, but the role of environmental and industrial contributors is equally critical. As evidence shows, bacteria do not require human aid to develop resistance—they naturally acquire and share resistance traits across species and environments. Therefore, even perfect clinical practice cannot halt resistance without broader systemic changes.

Policy changes must be globally harmonized. High-income countries must support low-income regions in monitoring and regulating antibiotic use. Surveillance systems should be expanded to track antibiotic use and resistance in both healthcare and agricultural settings. Investment in diagnostics is essential to ensure antibiotics are only used when necessary. Most importantly, public engagement must be improved—public campaigns, labeling regulations, and transparent food supply chains can raise awareness and promote responsible antibiotic use.

8. Conclusion

To prolong antibiotic effectiveness, a multi-pronged strategy is essential:
(1) Reduce agricultural dependence on antibiotics, substitute with alternatives, and enhance regulation.

(2) Enhance clinical practices through pharmacist involvement and prescription oversight;

(3) Increase public awareness and corporate accountability via education and legislation;

(4) Leverage AI and technology to accelerate the discovery and development of new antibiotics.

By coordinating across these domains, we can safeguard antibiotics for future generations and counter the escalating threat of resistant pathogens.

Disclosure statement

The author declares no conflict of interest.

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