RESEARCH PAPER

Antimicrobial resistance: mechanisms, clinical burden, and contemporary strategies for prevention and control

Antimicrobial Resistance: A narrative review

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ABSTRACT

Background: The effective prevention and treatment of infectious illnesses is under threat by antimicrobial resistance (AMR), which has grown to be a major worldwide health concern. The efficiency of current antimicrobial drugs has been reduced by the quick rise in resistant germs, which has also affected normal treatment decisions in both hospital and community settings. The goal of this review is to present complete and clinically relevant overview of antimicrobial resistance, with an emphasis on its epidemiology, mechanisms, contributory factors, health effects, and existing and new prevention and control techniques. **Methods:** Using electronic databases such as PubMed, Scopus, Web of Science, Google Scholar, and ScienceDirect, a narrative review of the literature was carried out. Included were English-language articles published between 2015 and 2026. Antimicrobial resistance, antibiotic resistance, multidrug resistance, antimicrobial stewardship, One Health, resistant pathogens, and global AMR burden were the search terms utilized. Policy documents and pertinent surveillance reports were also reviewed. **Findings:** The evidence suggests that antibiotic usage in agriculture, improper prescribing, self-medication, poor adherence, insufficient diagnostics, inadequate infection control, and environmental propagation of resistance genes are the main causes of AMR. Through processes like enzyme inactivation, target alteration, reduced permeability, efflux pumps, biofilm formation, and horizontal gene transfer, microorganisms acquire resistance. Treatment failures, extended hospital stays, higher healthcare expenses, and increased mortality rates are all effects of AMR. Controlling AMR still requires the use of tactics like surveillance, quick diagnostics, infection prevention, antimicrobial stewardship, and One Health-based methods.**In conclusion**, antimicrobial resistance is a complicated and quickly expanding challenge that calls for concerted efforts from the pharmaceutical, therapeutic, microbiological, environmental, and policy sectors. Rational antibiotic use, improved stewardship, thorough surveillance, infection prevention, and innovation in diagnostics and treatments are all necessary for the long-term management of AMR.

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1. INTRODUCTION

Modern medicine was revolutionized by the discovery and widespread application of antimicrobial medicines, which significantly decreased the morbidity and death linked to infectious diseases. Additionally, safe surgery, organ transplantation, infant care, chemotherapy, and critical care interventions have been made possible by effective antimicrobial therapy. However, antimicrobial resistance (AMR), a phenomena in which microbes evolve the capacity to survive exposure to antimicrobial treatments that were once successful against them, is posing an increasing danger to the long-term effectiveness of these advancements [1,2].

AMR has emerged as one of the world's most serious risks to public health. It makes it more difficult to treat common infections, prolongs sickness, raises healthcare expenses, and increases avoidable mortality. More significantly, AMR has increased reliance on reserve, more expensive, or toxic antimicrobial medicines and decreased the efficacy of empirical therapy [1,3]. Resistant microorganisms are becoming more common in community-acquired diseases, long-term care institutions, food systems, and environmental reservoirs, thus the problem is no

longer limited to tertiary hospitals or intensive care units [4,5].

Microbiological adaptability and human behavior interact in a complicated way to drive the development and spread of AMR. Resistance has been accelerated by inappropriate prescribing, the availability of over-the-counter antibiotics, self-medication, poor adherence, extended prophylaxis, insufficient infection prevention, and the use of antimicrobials in agriculture and livestock [2,6]. Furthermore, contaminated water systems, pharmaceutical waste, and hospital effluents all contribute to the environmental spread of resistance genes and organisms [5,7].

Methicillin-resistant Staphylococcus aureus (MRSA), vancomycin-resistant enterococci (VRE), extended-spectrum beta-lactamase (ESBL)-producing Enterobacterales, carbapenem-resistant Klebsiella pneumoniae, multidrug-resistant Pseudomonas aeruginosa, and drug-resistant Mycobacterium tuberculosis are some of the resistant pathogens that have emerged as significant therapeutic concerns [3,8]. These pathogens put a significant strain on healthcare systems around the world, complicate treatment, and restrict therapeutic alternatives. Given the scope and complexity of the issue, AMR should be considered a clinical, pharmacological, epidemiological, environmental, and policy challenge in addition to a microbiological one. Therefore, the current review offers a thorough and pharmacy-focused overview of antibiotic resistance, emphasizing its mechanisms, epidemiological burden, causes, implications, and current and emerging prevention and control techniques.

2. AIM OF THE REVIEW

The goal of the current review was to critically analyze the available data on antimicrobial resistance, with a focus on the following areas: major resistant pathogens, epidemiology and burden, molecular and biochemical mechanisms of resistance, clinical and public health implications, and the concept and classification of AMR. role of pharmacists and antimicrobial stewardship, as well as new and existing methods of prevention and control.

3. LITERATURE SEARCH STRATEGY

This manuscript was prepared using a narrative review design. PubMed, Scopus, Web of Science, Google Scholar, and ScienceDirect were used in an organized search of the literature. The search terms antimicrobial resistance, antibiotic resistance, multidrug resistance, mechanisms of resistance, resistant pathogens, antimicrobial stewardship, One Health, drug-resistant infections, and global AMR burden were combined to screen publications from 2015 to 2026.

Included were peer-reviewed original articles, review articles, surveillance reports, consensus documents, and policy publications pertinent to the review's purview. Studies and papers addressing epidemiology, resistance mechanisms, stewardship, diagnostics, prevention, and future treatment approaches were given priority. Excluded were duplicate records, non-English publications, conference abstracts without full text accessibility, and research that weren't clearly related to the review's goals.

4. CONCEPT AND CLASSIFICATION OF ANTIMICROBIAL RESISTANCE

The ability of bacteria to endure, proliferate, or persist in the face of exposure to antibiotic concentrations that would typically suppress or eradicate them is known as antimicrobial resistance. AMR is more general and encompasses resistance in bacteria, fungi, viruses, and parasites, despite the fact that the terms are often used interchangeably with antibiotic resistance [1,2].

There are two types of resistance: acquired and innate. A microorganism's intrinsic resistance is a naturally occurring trait that is frequently influenced by its physiological or structural characteristics. For example, certain Gram-negative bacteria have outer membrane barriers that prevent drugs from penetrating. Acquired resistance, on the other hand, arises gradually as a result of genetic mutation or the acquisition of resistance genes from other organisms [2,9].

In clinical settings, resistant organisms are frequently classified as:

- Multidrug-resistant (MDR): able to withstand at least one antimicrobial agent from three or more classes;
- Extremely drug-resistant (XDR): only vulnerable to one or two types;
- Pandrug-resistant (PDR): resistant to every kind of antibiotics now in use [10].

Because they have an impact on prognosis, infection control tactics, therapeutic choice, and the use of healthcare resources, these classifications are extremely important in clinical practice.

5. EPIDEMIOLOGY AND GLOBAL BURDEN OF AMR

AMR is a worldwide issue with significant clinical, financial, and developmental ramifications. Its burden is particularly heavy in low- and middle-income nations where the prevalence of infectious diseases is still high and there may be limited access to microbiological infrastructure, antimicrobial stewardship, diagnostics, and regulatory control [1,11].

Rising resistance in the pathogens causing urinary tract infections, respiratory infections, bloodstream infections, skin and soft tissue infections,

gastrointestinal infections, and healthcare-associated infections is indicative of the epidemiological impact of AMR [3,12]. Increasing resistance to beta-lactams, fluoroquinolones, macrolides, carbapenems, and even last-resort medications in certain situations has been reported in recent years [8,12].

Due to extensive antibiotic exposure, invasive procedures, extended hospital stays, and fragile patient populations, hospital environments continue to be significant reservoirs for the introduction and amplification of resistant bacteria. AMR is no longer limited to hospital settings, though. Reports of community-acquired resistance infections are becoming more common, particularly with regard to respiratory and uropathogens [6,13]. Inappropriate antimicrobial distribution, simple community access to antibiotics, uneven prescribing procedures, limited culture-based treatment, and poor infection control techniques all contribute to AMR in India and many other developing nations. In ordinary practice, the incidence of ESBL-producing Enterobacterales, methicillin resistance, and carbapenem resistance continue to present significant treatment problems [8,14].

Beyond its rapid effect on health, antimicrobial resistance (AMR) has a significant financial impact through raising treatment costs, increasing hospital stay, utilizing standard labs, and requiring more costly or hazardous alternative treatments. Additionally, it jeopardizes the sustainability of contemporary healthcare systems and impedes advancements in the management of infectious diseases [1,11].

6. MAJOR PATHOGENS ASSOCIATED WITH ANTIMICROBIAL RESISTANCE

Although a variety of microorganisms are involved in AMR, bacterial resistance is still the most clinically significant and extensively researched type. Gram-positive, Gram-negative, mycobacterial, fungal, viral, and parasitic pathogens can all be generally classified as resistant pathogens.

6.1 Gram-Positive Resistant Pathogens

Methicillin-resistant Staphylococcus aureus (MRSA) is still one of the most common Gram-positive bacteria that cause bacteremia, osteomyelitis, skin and soft tissue infections, and infections connected to devices [15]. Because MRSA diminishes the effectiveness of beta-lactam antibiotics and frequently calls for the use of glycopeptides or other backup medicines, it has gained therapeutic significance.

Another significant resistant category is vancomycin-resistant enterococci (VRE), which are more common in hospitalized, critically ill, and immunocompromised patients. Bloodstream infections, nosocomial transmission, and urinary tract infections are all linked to VRE [16].

6.2 Gram-Negative Resistant Pathogens

Because they can develop several resistance mechanisms, gram-negative bacteria are very dangerous. Among the significant pathogens are:

1.Escherichia coli
2.Pneumoniae Klebsiella
3.Aeruginosa pseudomonas
4.Baumannii Acinetobacter
5.Enterobacter species

ESBL generation, carbapenemase production, porin loss, efflux-mediated resistance, and biofilm-associated persistence are frequently observed in these organisms [8,17]. In critical care and inpatient settings, multidrug-resistant non-fermenters and carbapenem-resistant Enterobacterales have become serious risks.

6.3 Mycobacteria Resistant to Drugs

Drug-resistant Mycobacterium TB continues to be a serious worldwide issue. Both extensively drug-resistant tuberculosis (XDR-TB) and multidrug-resistant tuberculosis (MDR-TB) increase toxicity, lengthen therapy, complicate disease control, and lower treatment success [18].

6.4 Fungal, Viral, and Parasitic Resistance

AMR in fungi, viruses, and parasites is also therapeutically significant, even though bacterial AMR gets the most attention. Antiretroviral resistance in HIV, antiviral resistance in influenza, antimalarial resistance in Plasmodium falciparum, and azole-resistant Candida species including Candida auris are a few examples [19, 20]. These types of resistance highlight how widespread and dynamic AMR is.

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Table 1. Major resistant pathogens and their clinical relevance

Pathogen	Major Resistance Pattern	Common Clinical Relevance
Staphylococcus aureus	Methicillin resistance (MRSA)	Skin infections, bacteremia, osteomyelitis
Enterococcus faecium	Vancomycin resistance (VRE)	Nosocomial urinary and bloodstream infections
Escherichia coli	ESBL production, fluoroquinolon	Urinary tract infection, sepsis

	e resistance	
Klebsiella pneumoniae	ESBL, carbapenem resistance	Pneumonia, bloodstream infections
Pseudomonas aeruginosa	Multidrug resistance, efflux-mediated resistance	ICU infections, ventilator-associated pneumonia
Acinetobacter baumannii	Carbapenem resistance, biofilm-associated persistence	ICU and device-related infections
Mycobacterium tuberculosis	MDR/XDR resistance	Pulmonary and extrapulmonary tuberculosis
Candida auris	Azole and multidrug resistance	Invasive fungal and nosocomial infections

7. ANTIMICROBIAL RESISTANCE MECHANISMS

To withstand exposure to antibiotics, microorganisms use a variety of molecular and biochemical tactics. Clinically significant resistance is frequently the result of these mechanisms acting alone or in concert.

7.1 Inactivation of Drugs by Enzymes

The synthesis of enzymes that break down or chemically alter antimicrobial drugs is one of the most well-known resistance mechanisms. Classic examples of beta-lactamases include carbapenemases, ESBLs, AmpC enzymes, and narrow-spectrum beta-lactamases [9,17]. Depending on the enzyme subtype, these enzymes hydrolyze the beta-lactam ring, rendering penicillins, cephalosporins, monobactams, and carbapenems inactive. By phosphorylating, acetylating, or adenylating aminoglycoside antibiotics, aminoglycoside-modifying enzymes also decrease their activity [21].

7.2 Alteration of Drug Target Sites

Drug affinity and efficacy may be decreased by microorganisms acquiring mutations or structural alterations in antimicrobial target sites. Examples consist of:

- MRSA's modified penicillin-binding proteins,
- Modification of the ribosomal target leading to macrolide resistance,
- Topoisomerase IV and DNA gyrase mutations that contribute to fluoroquinolone resistance [15,21]. Because it frequently results in predictable cross-resistance among medication classes, target site modification is particularly important.

7.3 Diminished Permeability of Cells

Another significant mechanism is decreased absorption of antimicrobial drugs, especially in Gram-negative bacteria. Drug entry is decreased and intracellular antibiotic concentrations are lowered when outer membrane porins are altered or lost [17,21]. This mechanism is particularly important when it comes to beta-lactam and carbapenem resistance in non-fermenters and Enterobacterales.

7.4 Efflux pump

Antimicrobial drugs are actively expelled from microbial cells by efflux pumps, which are membrane-associated transport mechanisms. When they are overexpressed, intracellular medication concentrations may drop below therapeutic levels. Tetracyclines, macrolides, fluoroquinolones, chloramphenicol, and several other drugs have all been shown to cause efflux-mediated resistance [9,22].

7.5 Biofilm Formation

Structured microbial populations enmeshed in an extracellular polymeric matrix are called biofilms. Because of reduced drug penetration, changed metabolic activity, and increased persistence, organisms within biofilms are significantly less vulnerable to antimicrobial therapy [23]. Infections related to catheters, implants, prosthetic devices, and persistent wounds are areas where biofilm-associated resistance is especially important.

7.6 Transfer of Genes Horizontally

Through conjugation, transformation, and transduction, resistance determinants can spread quickly among bacteria. Because it makes it easier for plasmids, transposons, integrons, and resistance genes to spread between species and ecological niches, horizontal gene transfer is one of the most significant forces behind AMR evolution [24]. When taken as a whole, these mechanisms explain why resistance can develop quickly, endure under selection pressure, and become more challenging to overcome after it has been established.

Table 2. Major mechanisms of antimicrobial resistance

Mechanism	Description	Representative Example
Enzymatic inactivation	Drug destruction or chemical modification	Beta-lactamase production
Target site	Structural	Altered PBP in

alteration	modification reduces drug binding	MRSA
Reduced permeability	Decreased antimicrobial entry into the cell	Porin loss in Gram-negative bacteria
Efflux pumps	Active extrusion of drugs from the microbial cell	Tetracycline resistance
Biofilm formation	Protective microbial matrix reduces susceptibility	Device-related infections
Horizontal gene transfer	Transfer of resistance genes between organisms	Plasmid-mediated ESBL spread

Figure 1. Major Mechanisms of Antimicrobial Resistance

8. DRIVERS AND RISK FACTORS FOR AMR

A convergence of prescribing behavior, patient practices, healthcare system gaps, environmental exposure, and agricultural antimicrobial use sustains AMR.

8.1 Unsuitable Prescription

One of the main causes of AMR is still inappropriate prescription. This includes choosing suboptimal dose regimens, administering antibiotics for viral infections, utilizing drugs that are overly broad-spectrum, maintaining prolonged prophylaxis, and neglecting to de-escalate treatment once culture results are known [6,25].

8.2 Non-Prescription Access and Self-Medication

Antibiotics are either obtained without a legal prescription or are repurposed from unfinished regimens in numerous areas. Selective pressure favoring resistant organisms is created by this pattern, which promotes improper drug selection, improper dose, and insufficient treatment duration [14,26].

8.3 Inadequate Therapy Compliance

Partially suppressed bacteria may be able to persist and adapt if recommended antibiotic treatments are not followed. Poor treatment completion is still known to contribute to therapeutic failure and persistence, even though the link between adherence and AMR may differ depending on the pathogen and drug class [2,6].

8.4 Insufficient Prevention and Management of Infections

Particularly in healthcare settings, poor hand hygiene, overcrowding, inadequate sterilization, lax isolation procedures, and irregular environmental cleaning all contribute to the spread of resistant organisms [27].

8.5 Use of Antimicrobials in Agriculture and Animals

In veterinary medicine and food-producing animals, antimicrobials are utilized for growth promotion, prevention, and therapy. In addition to potentially facilitating the spread of resistant organisms via food chains, direct contact, and environmental pathways, such use may encourage resistance selection in animal reservoirs [4,28].

8.6 Spread of the Environment

Antimicrobial residues, resistant organisms, and resistance genes can be released into the environment via hospitals, pharmaceutical manufacture, wastewater systems, and agricultural runoff. These environmental reservoirs have the potential to maintain resistance and facilitate the spread of AMR outside of healthcare environments [5,7].

8.7 Limited Diagnostic Capacity

In settings where microbiological confirmation is delayed or unavailable, empirical therapy is often prolonged or unnecessarily broad. This increases antimicrobial exposure and contributes to avoidable selective pressure [12,29].

Table 3. Major drivers of antimicrobial resistance

Driver	Contribution to Resistance
Inappropriate prescribing	Unnecessary or suboptimal antimicrobial exposure
Self-medication	Incorrect drug selection and treatment duration
Poor adherence	Persistence of partially suppressed organisms
OTC antibiotic access	Unregulated antimicrobial misuse
Inadequate diagnostics	Prolonged broad-spectrum empirical therapy
Poor infection control	Spread of resistant organisms
Agricultural antimicrobial use	Selection pressure in animal reservoirs
Environmental contamination	Dissemination of resistant organisms and genes

Figure 02: Development And Spread Of Antimicrobial Resistance

9. AMR'S IMPACT ON CLINICAL AND PUBLIC HEALTH

Beyond microbiological resistance profiles, AMR has far-reaching effects. Resistant infections are linked to the following at the patient level: • A delayed recuperation, • Failure of treatment, • Repeated infection, • Extended hospital stays, • The requirement for harmful or reserve treatments, • And higher death rates [1,3,11]. Additionally, AMR makes rehabilitation more challenging. Clinicians may be compelled to employ less well-known, more costly, or more hazardous antibiotic regimens, which frequently necessitate closer observation and interdisciplinary cooperation. This is especially problematic for immunocompromised people, the elderly, juvenile populations, and critically ill patients [3,8]. At the level of the healthcare system, AMR leads to: • Extended hospital stays, • Rising expenses for microbiology and labs, • Increased pharmacy costs, • A higher burden of infection control, • As well as decreased bed turnover efficiency [11,27].

From a wider public health standpoint, AMR jeopardizes the efficacy of treatments such as surgery, transplantation, cancer chemotherapy, dialysis, intensive care, and neonatal care that rely on dependable antibiotic prophylaxis or treatment [1,3]. Therefore, the treatment of infectious diseases as well as the general safety of contemporary medicine are affected by the ongoing increase in AMR.

10. AMR AND THE ONE HEALTH PERSPECTIVE

The idea of "One Health" acknowledges the interdependence of environmental, animal, and human health. Because resistant organisms and resistance genes move dynamically across various interrelated areas, AMR is a classic One Health problem [4,5].

Strong selective pressure is created in human medicine by the overuse and abuse of antibiotics. Antimicrobial exposure can also encourage resistance bacteria in agricultural and veterinary settings. Resistance genes can survive and circulate outside of clinical settings due to environmental contamination from sewage, animal waste, pharmaceutical discharge, and healthcare effluents [5,7]. This interwoven environment significantly impacts the formulation of policies and interventions. Hospital governance is insufficient to effectively manage AMR. Clinicians, pharmacists, microbiologists, veterinarians, environmental scientists, legislators, regulators, and public health experts must work together to achieve sustainable containment [4,28].

The One Health framework, therefore, provides a more realistic and comprehensive approach to understanding and controlling AMR in the contemporary era.

Figure 3. One Health perspective of antimicrobial resistance

11. ANTIMICROBIAL STEWARDSHIP: A PHARMACY AND CLINICAL VIEW

Coordinated actions intended to enhance and monitor the proper use of antimicrobial agents are referred to as antimicrobial stewardship. Optimizing clinical outcomes while reducing toxicity, expense, and the development of resistance is its main objective [25, 30].

11.1 Fundamentals of Stewardship

The following are the main goals of antimicrobial stewardship: • The right choice of antibiotics, • The right dosage, • The proper administration route, • The ideal length of treatment, • As well as prompt de-escalation or termination where necessary [25]. Treatment withholding is not the definition of stewardship. Instead, it seeks to guarantee that antimicrobial therapy is evidence-based, safe, targeted, and justified.

11.2 Crucial Stewardship Measures

Typical stewardship initiatives consist of: • Preauthorization and formulary limitation, • A prospective audit with comments, • Prescribing according to guidelines, • Protocols for switching from intravenous to oral • "Time-outs" for antibiotics • Optimization of dosage • Additionally, de-escalation led by culture [25, 30]. These tactics have been linked to better prescription quality, less needless exposure to antibiotics, and more sensible use of antibiotics.

11.3 The Pharmacist's Function

For pharmacy-focused journals like JYP, the pharmacist's role in stewardship is especially significant. Pharmacists make a contribution by: • Checking the appropriateness of prescriptions, • Suggested dosage modifications, • Finding interactions and duplications, • Assisting in the optimization of renal and hepatic doses, • Supporting decisions regarding de-escalation, • Analyzing antibiograms and recommendations, • And instructing patients and prescribers [30, 31].

Pharmacists are in a strategic position to enhance patient counseling regarding adherence and rational therapy, decrease inappropriate dispensing, and

improve antimicrobial use in both hospital and community settings.

11.4 Outpatient Relevance and Community Pharmacy

A significant amount of antibiotic exposure takes place outside of hospital environments. Consequently, tertiary institutions shouldn't be the exclusive setting for stewardship. Community pharmacists and outpatient physicians play crucial roles in recognizing overuse, fostering public awareness, enforcing prescription compliance, and preventing needless antibiotic usage [26, 31].

12. AMR DETECTION AND SURVEILLANCE

The cornerstones of AMR control are prompt diagnosis and efficient surveillance. Antimicrobial prescribing is often empirical, time-consuming, and unduly wide in the absence of solid microbiological evidence and local resistance data [12,29].

12.1 Traditional Diagnostic Techniques

AMR detection still heavily relies on standard microbiological techniques. Among them are: • Sensitivity and culture testing, Diffusion of disks,
• Techniques for diluting broth
• Determining the minimum inhibitory concentration (MIC),
• and the identification of phenotypic resistance [29].

Depending on the organism and material, these methods may take 24 to 72 hours or more, although they are nonetheless therapeutically effective.

12.2 Quick and Sophisticated Diagnostics

Resistance detection is becoming faster and more accurate thanks to emerging technologies. Among them are: PCR, or polymerase chain reaction,
• Assays for multiplex molecular
• Mass spectrometry using MALDI-TOF
• Sequencing the entire genome,
• As well as metagenomic methods [12,32].

These techniques can improve outbreak detection and resistance mapping, decrease needless broad-spectrum use, and facilitate faster targeted therapy.

12.3 Monitoring Systems

AMR surveillance supports public health planning, identifies resistance trends, directs empirical treatment, and influences formulary choices. At the local, institutional, regional, national, or international levels, surveillance may take place [1,11]. Because they provide logical empirical selection based on local resistance patterns, hospital antibiograms continue to be particularly useful in clinical practice. Additionally, broader surveillance systems aid in tracking new resistance concerns and assessing the results of infection control and stewardship initiatives [11,29].

13. EXISTING AND NEW METHODS TO FIGHT AMR

AMR cannot be controlled with a single intervention. Clinical, pharmacological, public health, regulatory, and scientific approaches must all be used for sustainable containment.

13.1 Reasonable Prescription and Enforcement of Policies

The most practical approach is still to improve the prescription of antibiotics. Reducing needless or inappropriate antimicrobial exposure can be achieved by standard treatment recommendations, prescription audits, stewardship rounds, ongoing professional education, and restricted dispensing regulations [25,26].

13.2 Prevention and Management of Infections

Antimicrobial need is decreased by hand hygiene, sterilization, environmental cleaning, vaccination, isolation measures, catheter care, and surgical infection prevention [27].

13.3 Immunization

By lowering the prevalence of infectious disorders that would otherwise necessitate antibiotic therapy, vaccination indirectly aids in the control of AMR. Additionally, it reduces the potential for resistant infections to spread [33].

13.4 Quick Diagnostics

Quick diagnosis can prevent needless empirical broad-spectrum medication, enable early focused therapy, and help differentiate bacterial from non-bacterial illness [12,32].

13.5 Creation of Novel Antimicrobial Substances

Continued investment in novel antibiotics and antifungal drugs is crucial, even though the pipeline for antimicrobial development is still small in comparison to the extent of resistance. But without the introduction of novel agents within a robust stewardship framework, innovation is insufficient on its own [34].

13.6 New and Alternative Treatment Methods

Numerous novel or cutting-edge strategies are being researched, such as: • The use of bacteriophages
• Peptides that are antimicrobial
• Anti-biofilm tactics,
• Treatments focused on the host,
• Antimicrobial strategies based on CRISPR,
• Modulation of the microbiome
• Additionally, antibacterial delivery aided by nanotechnology [35–37].

These strategies are still at different phases of development, but they could play a bigger role in managing resistant infections in the future.

Table 4. Key strategies for prevention and control of AMR

Strategy	Practical Relevance
Antimicrobial stewardship	Optimizes selection, dose, route, and duration

Infection prevention and control	Reduces transmission of resistant pathogens
Culture and susceptibility testing	Supports targeted therapy
Vaccination	Reduces infectious disease burden and antibiotic use
Public education	Promotes responsible antimicrobial use
Hospital antibiogram use	Guides rational empirical treatment
Regulatory control	Limits inappropriate dispensing and misuse
One Health interventions	Addresses AMR across human, animal, and environmental domains

14. DIFFICULTIES IN CONTAINING AMR

Effective AMR control is still challenging in practice despite growing knowledge. Among the main obstacles are: • Inadequate microbiological infrastructure
• Inadequate application of stewardship
• Inconsistent clinician compliance with recommendations,
• Low public awareness,
• Access to antibiotics without a prescription,
• Disjointed surveillance
Inadequate enforcement of regulations
Technical and financial obstacles to the development of new antibiotics [11, 26, 34].
AMR solutions get worse by fragmented accountability in many hospital settings. Resistance mitigation becomes irregular and unsustainable when clinicians, pharmacists, microbiologists, infection control teams, and administrators do not work together.

The gap between implementation and knowledge is another difficulty. Even while the mechanisms and effects of antimicrobial resistance (AMR) are becoming more understood, the evidence has not yet been fully incorporated into normal prescription practices, community behavior, or policy enforcement.

15. VIEWS FOR THE FUTURE

Precision diagnostics, genetic surveillance, digital health tools, and increased stewardship outside of tertiary care settings will probably be key components of AMR control in the future. Potential future paths consist of: • Antimicrobial decision support with AI assistance,
• Hospital resistance dashboards in real time,
• Tracing outbreaks using genome information,
• Precision treatment for infectious diseases,
• Monitoring environmental resistance,
• and more robust governance mechanisms based on One Health [32, 35].
Crucially, maintaining the efficacy of current medications through sensible, responsible, and evidence-based use will be just as important to the long-term success of AMR control as the development of new medications.

16. DISCUSSION

The current analysis emphasizes that antibiotic resistance is a systems-level dilemma influenced by therapeutic behavior, healthcare infrastructure, ecological exposure, and regulatory practice ratherthan only a microbiological adaptation. The growing prevalence of multidrug-resistant Gram-negative bacteria, especially in hospital settings, is a recurrent theme in the literature. These organisms often combine multiple resistance mechanisms, which complicates empirical treatment and significantly restricts therapeutic flexibility [8,17]. AMR is no longer a problem limited to specialized or inpatient settings, as seen by the rise in community-associated resistance infections [6,13].

Another crucial finding is that AMR is caused by both inappropriate and excessive usage of antibiotics. In clinical pharmacy and prescription practice, this distinction is particularly important. Significant resistance pressure can still result from improper agent selection, needless length, lack of de-escalation, and disregard for diagnostic evidence, even in cases where antimicrobial therapy is clinically required [25, 30].
Some of the most useful and effective therapies are not always the most technologically sophisticated from the standpoint of pharmacy and healthcare delivery. The most practical and scalable methods for AMR containment in the real world continue to include stewardship, culture-guided therapy, local antibiogram usage, pharmacist-led medication review, patient education, and infection prevention [27,30,31].

Additionally, the analysis shows that a One Health paradigm, as opposed to discrete clinical interventions, should be used to address AMR. Interdisciplinary cooperation is crucial because resistant organisms and genes travel across human, animal, and environmental domains [4,5,28]. When considered collectively, the research lends credence to the idea that AMR is a problem for both

science and governance. In addition to innovation, systems-level execution, accountability, and logic will be necessary for sustainable control.

17. CONCLUSION

One of the most significant and intricate risks facing contemporary healthcare is antimicrobial resistance. In addition to increasing therapeutic uncertainty, prolonging hospital stays, increasing healthcare expenses, and jeopardizing the safety of numerous standard and cutting-edge medical procedures, it also impairs the treatment of infectious diseases. Microbial adaptation, irrational antibiotic usage, poor diagnoses, inadequate infection control, agricultural exposure, and environmental transmission all contribute to the emergence and spread of AMR. Different mechanisms used by resistant microorganisms make therapy more challenging and diminish the long-term efficacy of current treatments. A coordinated and long-term approach that incorporates antimicrobial stewardship, prudent prescription, pharmacist involvement, microbiological surveillance, infection prevention, public awareness, regulatory enforcement, and One Health-based policy action is necessary for the effective containment of AMR.

Maintaining antibiotic efficacy is both a public health responsibility and a therapeutic requirement. The responsible use, monitoring, and protection of antimicrobial agents will determine how infectious diseases are managed in the future.

18. REVIEW LIMITATIONS

There are some restrictions on this review. Formal meta-analysis and PRISMA-based quantitative synthesis are not included because it employs a narrative rather than a systematic review design. Some regional or non-English publications might have been overlooked because only English-language literature was taken into account. Furthermore, resistance patterns and therapeutic advancements may continue to evolve after the period covered by the reviewed literature because AMR is a constantly developing subject.

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21. CONFLICT OF INTEREST

The authors declare no conflict of interest.

22. ETHICAL APPROVAL

Ethical approval was not required for this study because it is based exclusively on previously published literature.

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