

Antimicrobial Resistance As A Global Public Health Challenge: Mechanisms, Drivers, Surveillance And Integrated Control Strategies

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Abstract

Antimicrobial resistance (AMR) is a rapidly intensifying public health problem that compromises the treatment of common infections, raises the risk of complications after surgery and other medical interventions, and increases health-care costs. This narrative review synthesizes current evidence on the biological mechanisms, major human and system-level drivers, clinical and socioeconomic consequences, surveillance approaches, and priority interventions for AMR control. Peer-reviewed literature and authoritative reports from the World Health Organization (WHO), the Centers for Disease Control and Prevention, the European Centre for Disease Prevention and Control, and other international sources were considered, with emphasis on evidence published from 2000 to 2026. Resistance emerges through chromosomal mutation and acquisition of mobile genetic elements and is amplified by inappropriate antimicrobial exposure, inadequate infection prevention and control, delayed microbiological diagnosis, and antimicrobial use across human, animal, food and environmental sectors. Recent WHO surveillance indicates that approximately one in six laboratory-confirmed bacterial infections worldwide was resistant to antibiotics in 2023, while bacterial AMR was associated with more than 4.7 million deaths in 2021. Effective containment therefore requires an integrated One Health response combining antimicrobial stewardship, rapid and quality-assured diagnostics, infection prevention and control, vaccination, surveillance, responsible antimicrobial use in agriculture and veterinary practice, public education, and sustained research and development. Strengthening national surveillance and linking resistance data with antimicrobial consumption are particularly important for translating global recommendations into locally effective public health action.

Keywords: antimicrobial resistance; antibiotic resistance; antimicrobial stewardship; One Health; surveillance; infection prevention and control; public health

Introduction

Antimicrobial resistance (AMR) occurs when microorganisms no longer respond adequately to antimicrobial medicines, making infections more difficult to treat and increasing the risks of severe illness, transmission, disability and death [1,31]. Although resistance is a natural evolutionary phenomenon, its emergence and spread are accelerated by antimicrobial exposure and by failures in prescribing, infection prevention, sanitation, diagnostic capacity and surveillance [4–7].

The public health implications of AMR extend well beyond infectious-disease practice. Effective antibiotics underpin modern surgery, intensive care, cancer chemotherapy, transplantation, neonatal care and the management of immunocompromised patients. As resistance increases, routine medical procedures become more hazardous and health systems face longer hospital stays, greater use of intensive care, more expensive second-line or reserve medicines and additional diagnostic requirements [7,21,31].

The global burden is substantial. WHO reported in 2026 that bacterial AMR was associated with more than 4.7 million deaths worldwide in 2021. WHO's 2025 global surveillance report further showed that approximately one in six laboratory-confirmed bacterial infections worldwide was resistant to antibiotics in 2023 [31,32]. These findings reinforce the need to treat AMR not solely as a microbiological problem but as a multisectoral public health and health-security challenge.

The aim of this review is to synthesize current evidence on the mechanisms and drivers of AMR, its clinical and socioeconomic consequences, and the principal surveillance and control strategies required for an integrated public health response.

Materials And Methods

This article was prepared as a narrative and integrative review. Peer-reviewed publications and authoritative international reports addressing antimicrobial resistance were examined. The evidence base included literature indexed in PubMed, Scopus and Web of Science, together with documents and technical guidance issued by WHO, CDC, ECDC and other recognized international institutions.

Priority was given to systematic reviews, meta-analyses, clinical and epidemiological studies, surveillance reports, consensus documents and major policy guidance published mainly between 2000 and 2026. Earlier landmark publications were retained when they were important for explaining established resistance mechanisms or the historical development of AMR control.

The literature was synthesized using content analysis, comparison and thematic integration. Evidence was organized into six domains: molecular and genetic mechanisms; drivers of resistance; clinical and socioeconomic consequences; antimicrobial stewardship and diagnostic stewardship; infection prevention and control; and surveillance and One Health interventions. Because this was a narrative review, no pooled effect estimate or formal meta-analysis was undertaken.

Results And Discussion

1. Biological and molecular mechanisms of antimicrobial resistance

AMR is a dynamic evolutionary process. Microorganisms can acquire resistance through spontaneous chromosomal mutations or through horizontal transfer of resistance determinants carried by plasmids, transposons and integrons [6,17–19,28,29]. These genetic events are selected and amplified when antimicrobial exposure suppresses susceptible organisms while resistant subpopulations survive and proliferate.

Major phenotypic mechanisms include enzymatic inactivation of antimicrobial agents, alteration or protection of drug targets, reduced membrane permeability, active efflux, metabolic bypass and biofilm-associated tolerance [8,28,29]. Horizontal gene transfer through conjugation, transformation and transduction enables resistance determinants to move between bacterial strains and, in some circumstances, across species and ecological niches [17–19]. This capacity for rapid genetic exchange helps explain why resistance can spread through hospitals, communities, food systems, animals and the environment.

2. Major drivers: antimicrobial use and health-system factors

Inappropriate and excessive antimicrobial use remains one of the strongest modifiable drivers of resistance [4,5,7]. Clinically important examples include antibiotic treatment of viral illnesses, unnecessary broad-spectrum therapy, incorrect dosing, prolonged prophylaxis, failure to review empirical therapy after microbiological results become available, and unrestricted access to antibiotics without adequate professional oversight.

At the same time, AMR policy must avoid a simplistic 'use less' message. In many low- and middle-income settings, inappropriate use coexists with inadequate access to effective, quality-assured antibiotics. WHO data on antibiotic use demonstrate wide differences between countries and highlight both overuse and under-access. The WHO AWaRe framework therefore seeks to improve the quality of antibiotic use by increasing appropriate use of Access-group antibiotics while preserving Watch and Reserve agents [9,33].

Health-system conditions can intensify selection and transmission. Delayed diagnostics encourage prolonged empirical treatment; shortages of trained personnel weaken stewardship; poor water, sanitation and hygiene facilitate infection transmission; and insufficient isolation capacity or inconsistent hand hygiene can accelerate the spread of multidrug-resistant organisms in health-care facilities [13,16,25].

3. One Health dimensions of AMR

Antimicrobial use in animal health, food production and agriculture contributes to a shared ecological reservoir of resistance. Resistant organisms and resistance genes can circulate among humans, animals, food products, wastewater, soil and other environmental compartments [5,7,18]. Consequently, interventions restricted to hospitals cannot fully address the problem.

A One Health approach links human medicine, veterinary practice, food safety, agriculture and environmental management. Core priorities include prudent antimicrobial use in animals, prevention of infection through vaccination and biosecurity, surveillance across sectors, safe waste and wastewater management, and coordinated policies that reduce unnecessary antimicrobial exposure without compromising access to essential treatment.

4. Clinical and socioeconomic consequences

Drug-resistant infections are associated with treatment failure, delayed effective therapy, increased risk of severe disease and sepsis, longer hospitalization and greater use of intensive care [6,20,31]. Resistance can also force clinicians to use agents that are more toxic, more expensive or less readily available. The consequences are especially serious for vulnerable patients and for procedures that depend on reliable antimicrobial prophylaxis.

The economic burden extends from direct medical expenditure to productivity losses and broader effects on health-system resilience and economic development [21]. For health services, AMR increases laboratory costs, bed occupancy, staff workload and expenditure on second-line and reserve medicines. These effects make prevention and early detection economically relevant as well as clinically necessary.

5. Antimicrobial stewardship and diagnostic stewardship

Antimicrobial stewardship programmes (ASPs) are structured interventions designed to optimize antimicrobial selection, dose, route and duration while preserving clinical outcomes and minimizing avoidable resistance [9,10,14]. Effective programmes commonly combine evidence-based prescribing guidelines, prospective audit and feedback, formulary measures, review of therapy at 48–72 hours, dose optimization, de-escalation when appropriate, and monitoring of antimicrobial consumption and resistance patterns.

Stewardship is most effective when supported by timely diagnostics. Conventional culture and antimicrobial susceptibility testing remain fundamental, while rapid molecular and other diagnostic technologies can shorten the interval between clinical presentation and targeted therapy [15,24]. Diagnostic stewardship additionally emphasizes correct test selection, specimen quality, appropriate timing, interpretation and communication of results. This reduces both missed infections and unnecessary antimicrobial exposure.

WHO's current antibiotic-use strategy also emphasizes the AWaRe classification. The global target endorsed at the 2024 United Nations high-level meeting calls for at least 70% of human antibiotic use globally to come from the Access group by 2030, reflecting an effort to align access, effectiveness and resistance containment [33].

6. Infection prevention and control

Preventing infection reduces the need for antimicrobial treatment and therefore reduces opportunities for resistance selection. In health-care settings, hand hygiene, environmental cleaning, sterilization and disinfection, safe invasive-device practices, appropriate isolation or cohorting, and surveillance of health-care-associated infections are central measures [13,16,25].

Vaccination is also an AMR intervention. By preventing bacterial infections directly and reducing viral illnesses that can lead to inappropriate antibiotic prescribing or secondary bacterial complications, immunization can reduce antimicrobial consumption and transmission. Water, sanitation and hygiene interventions have a similar population-level effect by lowering infectious-disease incidence.

7. Surveillance and the role of GLASS

Surveillance converts laboratory findings into public health intelligence. WHO launched the Global Antimicrobial Resistance and Use Surveillance System (GLASS) to standardize the collection, analysis and sharing of national AMR and antimicrobial-use data [12,26,32]. GLASS has progressively expanded from routine bacterial resistance surveillance to antimicrobial consumption, emerging resistance, fungal infections and One Health-oriented modules.

The 2025 WHO global antibiotic resistance surveillance report drew on more than 23 million bacteriologically confirmed cases, with 104 countries reporting 2023 data and 110 countries contributing data for the 2016–2023 period [32]. Such standardized surveillance supports comparison of resistance patterns, detection of emerging threats, development of empirical treatment guidance and evaluation of interventions.

For national systems, surveillance quality is as important as surveillance coverage. Reliable microbiology laboratories, standardized susceptibility testing, clinical and epidemiological metadata, quality assurance, representative sampling and linkage between resistance and antimicrobial-consumption data are necessary to avoid misleading estimates and to guide local prescribing policy.

8. An integrated public health framework for AMR control

The evidence supports a coordinated package rather than isolated interventions. At the health-care facility level, stewardship should be linked to microbiology, infection prevention and control, pharmacy data and clinical governance. At the population level, surveillance, vaccination, public communication, regulation of antimicrobial distribution and access to quality-assured medicines are essential.

At the multisectoral level, One Health governance should connect human health, veterinary services, agriculture, food safety and environmental authorities. Research and development remain necessary for new antimicrobials, vaccines and diagnostics, but innovation cannot substitute for preserving the effectiveness of existing medicines [30,31]. Sustainable financing, workforce development and measurable national targets are therefore critical components of AMR preparedness.

Conclusion

Antimicrobial resistance is a complex biological, clinical, epidemiological and socioeconomic challenge. Its development is accelerated by inappropriate antimicrobial exposure, but its spread and impact are also shaped by diagnostic capacity, infection prevention, health-system organization, access to quality medicines, agricultural practices and environmental pathways.

Effective control requires an integrated public health strategy built around antimicrobial and diagnostic stewardship, strong microbiology services, infection prevention and control, vaccination, standardized surveillance, responsible antimicrobial use across sectors and One Health coordination. Current WHO surveillance demonstrates that AMR is already widespread rather than a distant future threat. National programmes should therefore prioritize high-quality surveillance linked to antimicrobial-use data and translate these findings into locally adapted prescribing, prevention and policy interventions.

Declarations

Ethics statement: This article is a narrative review of published literature and publicly available reports. It did not involve recruitment of human participants, collection of identifiable personal data, or animal experimentation; therefore, institutional ethics approval was not required.

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