

Antimicrobial Resistance : An Overview

Ms. Gayatri A. Kamble¹, Ms Neha J. Muttelwar², Ms. Achal H. Raghute³

^{1,2}Student, Dr. Arun Motghare college of Pharmacy, Kosra-Kondha (MH) – 441908

³Assistant Professor, Dr. Arun Motghare college of Pharmacy, Kosra-Kondha (MH) – 441908

Abstract

Resistance to antimicrobial treatments decreases the effectiveness of these medications, resulting in higher rates of illness, death, and healthcare costs. Due to globalization, any country is more exposed to diseases that emerge elsewhere, making resistance a serious threat to global public health. No single nation can fully safeguard its population from this issue on its own. Therefore, international cooperation is crucial. However, the responsibility for health care remains mainly within national borders. As a result, there is a notable gap between the challenges and solutions related to antimicrobial resistance and the existing systems and structures in place to address them.

This paper examines the ability of national and international organizations and structures to work together in response to antimicrobial resistance.

It outlines strategies for managing resistance, especially those that involve coordinated efforts among countries. The paper also evaluates how well national and international responses are meeting the needs, and it highlights the actions that global organizations could take to overcome current challenges. Suggestions are made for ways to promote international cooperation in the fight against antimicrobial resistance.

Keywords: Drug resistance, Microbial; Anti-infective agents; Drug utilization; Drug and narcotic control; Research; International cooperation (source: MeSH, NLM).

Mots clefs Resistance microbienne aux médicaments; Anti-infectieux; Utilisation médicament; Contrôle drogues et stupéfiants; Recherche; Coopération internationale (source: MeSH, INSERM).

Palabras clave Resistencia microbiana a las drogas; Agentes antiinfecciosos; Utilización de medicamentos; Control de medicamentos y narcóticos; Investigación; Cooperación internacional (fuente: DeCS, BIREME).

Introduction

The growing problem of antimicrobial resistance, where many bacteria that cause serious diseases in humans are becoming resistant to multiple antibiotics, and the movement of this resistance from hospitals into the wider community, are increasingly seen as a major danger to public health.

New ways for bacteria to become resistant, the development of resistance to multiple drugs, and the ease with which bacteria can share resistance genes between different species, all contribute to a growing sense of helplessness.

Diseases that were once manageable with antibiotics now seem more difficult to treat.

Some reports that portray alarming scenarios, like the return of deadly plagues or women dying from childbirth infections, tend to heighten public fear rather than help address real public health issues.

Unfortunately, these kinds of sensationalized stories are not rare and are often spread by media outlets aiming to boost readership.

The use of antibiotics — whether in humans, animals, plants, or food production — can eventually lead to bacterial resistance.

Even though more articles are now discussing this topic, there is still very little understanding of the specific conditions under which antibiotics promote or reduce the growth of resistant bacteria.

Once resistance develops, it can spread across different environments and countries.

Scientific research on resistance has been limited for many years, with recent efforts only beginning to pick up again due to increasing worries. The lack of scientific data puts society and policy makers in a difficult position, forcing them to take action without fully understanding the causes.

this situation is made worse by the slow pace, and in some areas the near disappearance, of discoveries and development of new antibiotics with novel ways to fight infections.

This has created a sense of urgency, even if the actions taken may not be fully effective.

Globalization, changes in trade systems, and the movement of resistant bacteria through international travel and trade in animals and food products increase the global risk of spreading resistance.

This also raises the possibility of countries imposing unnecessary trade restrictions based on poorly evaluated or misunderstood risks. The first chapter focuses on the implementation of waste management systems in modern cities, emphasizing the importance of a responsive and predictive system. The integration of Internet of Things (IoT), Artificial Intelligence (AI), and blockchain can create an "autonomous waste ecosystem" that operates in real-time. At the first level, IoT provides the infrastructure through sensor-equipped smart bins. These sensors measure waste levels, temperature, humidity, and even the type of waste using ultrasonic, thermal, and gas sensors (Dari et al., 2025). Data from these sensors is transmitted via 5G networks to the cloud. This system has been successfully implemented in Barcelona, reducing operational costs by up to 25%, although it currently relies only on IoT without AI or blockchain (Kurniawan et al., 2025).

The second layer involves AI, which processes the data to make predictions and automate decisions.

Supervised learning models can predict when bins will be full, while clustering algorithms can analyze daily waste consumption trends to identify patterns in community behaviour (Ginting & Apnena, 2023). AI also optimizes waste collection routes, ensuring that trucks only travel to locations that genuinely require emptying. A similar system, tested in Seoul, demonstrates a 30% reduction in truck travel distance through predictive algorithms. According to an IEEE study, the integration of IoT, AI, and blockchain can significantly enhance waste management efficiency and sustainability in modern urban settings.

IMPACT OF ANTIBIOTIC RESISTANCE

The impact of antibiotic resistance in terms of mortality and public health cost is quite difficult to estimate, and there are few studies addressing this issue. The US Center for Disease Control and Prevention (CDC) conservatively estimated that, in the US, more than two million people every year are affected with antibiotic-resistant infections, with at least 23,000 dying as a result of the infection. In Europe, each year, the number of infections and deaths due to the most frequent multidrug-resistant bacteria (*S. aureus*, *Escherichia coli*, *Enterococcus faecium*, *Streptococcus pneumoniae*, *Klebsiella pneumoniae* and *Pseudomonas aeruginosa*) was estimated at around 400,000 and 25,000, respectively, in 2007. Several fields of modern medicine depend on the available.

CAUSES

AMR is driven largely by the misuse and overuse of antimicrobial. Yet, at the same time, many people around the world do not have access to essential antimicrobial. This leads to microbes either evolving a defense against drugs used to treat them, or certain strains of microbes that have a natural resistance to antimicrobials becoming much more prevalent than the ones that are easily defeated with medication. While antimicrobial resistance does occur naturally over time, the use of antimicrobial agents in a variety of settings both within the healthcare industry and outside of has led to antimicrobial resistance becoming increasingly more prevalent.

Although many microbes develop resistance to antibiotics over time through natural mutation, overprescribing and inappropriate prescription of antibiotics have accelerated the problem. It is possible that as many as 1 in 3 prescriptions written for antibiotics are unnecessary. Every year, approximately 154 million prescriptions for antibiotics are written. Of these, up to 46 million are unnecessary or inappropriate for the condition that the patient has. Microbes may naturally develop resistance through genetic mutations that occur during cell division, and although random mutations are rare, many microbes reproduce frequently and rapidly, increasing the chances of members of the population acquiring a mutation that increases resistance.

Many individuals stop taking antibiotics when they begin to feel better. When this occurs, it is possible that the microbes that are less susceptible to treatment still remain in the body. If these microbes are able to continue to reproduce, this can lead to an infection by bacteria that are less susceptible or even resistant to an antibiotic. There have been increasing public calls for global collective action to address the threat, including a proposal for an international treaty on antimicrobial resistance. Further detail and attention is still needed in order to recognize and measure trends in resistance on the international level; the idea of a global tracking system has been suggested but implementation has yet to occur. A system of this nature would provide insight to areas of high resistance as well as information necessary for evaluating programs, introducing interventions and other changes made to fight or reverse antibiotic resistance.

PREVENTION

Duration of antimicrobials Delaying or minimizing the use of antibiotics for certain conditions may help safely reduce their use. Antimicrobial treatment duration should be based on the infection and other health problems a person may have. For many infections once a person has improved there is little evidence that stopping treatment causes more resistance. Some, therefore, feel that stopping early may be reasonable in some case. Other infections, however, do require long courses regardless of whether a person feels better. Delaying antibiotics for ailments such as a sore throat and otitis media may have no difference in the rate of complications compared with immediate antibiotics, for example. When treating respiratory tract infections, clinical judgement is required as to the appropriate treatment (delayed or immediate antibiotic use).

Public Health England reported that the total number of antibiotic resistant infections in England rose by 9% from 55,812 in 2017 to 60,788 in 2018, but antibiotic consumption had fallen by 9% from 20.0 to 18.2 defined daily doses per 1,000 inhabitants per day between 2014 and 2018.

FACTORS CONTRIBUTING TO THE EMERGENCE OF ANTIBIOTIC RESISTANCE

Antibiotic resistance is a natural phenomenon that occurs when microorganisms are exposed to antibiotic drugs. Under the selective pressure of antibiotics, susceptible bacteria are killed or inhibited, while bacteria

that are naturally (or intrinsically) resistant or that have acquired antibiotic-resistant traits have a greater chance to survive and multiply. Not only the overuse of antibiotics but also the inappropriate use (inappropriate choices, inadequate dosing, poor adherence to treatment guidelines) contribute to the increase of antibiotic resistance.

Antibiotic resistance in human medicine

In the community of affluent countries, the excessive prescription by general practitioners, even in the absence of appropriate indications, plays an important role in the inappropriate use of antibiotics. Diagnostic uncertainty often fosters over-prescription especially when the clinical picture of viral or bacterial aetiology is similar. Self-medication (see below) also plays an important part.

In many developing countries, excessive use is due to the easy availability of antimicrobial drugs that can be purchased without prescription of a physician or other qualified health professional. In both situations, there is the perception that antibiotics are the “wonder drugs” that can rapidly cure any kind of ailments.

In the hospital setting, the intensive and prolonged use of antimicrobial drugs is probably the main contributor to the emergence and spread of highly antibiotic-resistant nosocomial infections; but other factors can play an important role: presence of highly susceptible immunosuppressed patients (e.g. AIDS patients, cancer patients, or transplant recipients) and fragile elderly patients, invasive surgical procedures and intensity of clinical therapy, lengthy of stay in hospital,¹⁰ failure to control infections spread from patient to patient.

- Antibiotic consumption in the community and in hospital settings

The annual report of the European Surveillance of Antimicrobial Consumption Network (ESAC-Net) reported that in Europe during 2012 the consumption in the community of antibacterials for systemic use [Anatomical Therapeutic Chemical (ATC) group J01], ranged from 11.3 (the Netherlands) to 31.9 (Greece) defined daily doses (DDD) per 1000 inhabitants per day. In all ESAC-Net reports, a geographic gradient in the amount of antibiotics used can be noted, with higher DDD in the South of Europe. In 2012, the beta-lactams/penicillin group (ATC J01C) accounted for 50% of the consumption of antibacterials for systemic use and amoxicillin, alone or in combination with clavulanic acid, was the antibacterial agent most often used in almost all countries, with the exception of Norway and Sweden where the most used agent was phenoxymethylpenicillin.

In the hospital sector ESAC-Net estimated that in 2012, the population-weighted EU/EEA mean consumption for systemic use of antibacterials was 2.0 DDD per 1000 inhabitants, ranging from 1.0 DDD per 1000 inhabitants per day in the Netherlands, to 2.8 in Finland. Also in the hospital setting, the beta-lactams/penicillin group was most often used, accounting for 29.3% of all the consumption of antibacterials for systemic use.¹¹

According to a recent point prevalence survey on healthcare associated infections in Europe, 35.0% of the hospitalised patients in 2011 were receiving antibiotics.¹²

In the US, healthcare providers prescribed 258.0 million courses of antibiotics (833 prescriptions per 1000 persons) in 2010. Penicillin (23%) and macrolides (22%) were the most common categories prescribed. The most frequently prescribed antibiotic agents were azithromycin and amoxicillin.¹³

Large-scale assessments of antimicrobial use in hospitals in the USA are derived from studies conducted in groups of acute care hospitals.^{14,15} According to one of these studies, a mean of 59.3% of all patients received at least one dose of an antimicrobial agent during their hospital stay.¹⁴

- Incorrect knowledge about antibiotics in the population and self-medication

Many studies indicate lack of knowledge about antibiotics in the general population, specifically incorrect knowledge about the activity of antibiotics on bacteria and viruses, insufficient awareness about antibiotic resistance and about the adverse effects of antibiotics.

A survey, carried out in 2009, on the use and on the knowledge of antibiotics among European citizens, revealed that 20% of the people interviewed admitted they had taken antibiotics to treat flu-like symptoms, although they knew that antibiotics do not act against viruses. In addition, 14% also said that they had taken antibiotics to treat a common cold.¹⁶

A survey among adults in the United Kingdom showed that 38% of respondents did not know that antibiotics do not work against most coughs or colds.¹⁷ On the contrary, in Sweden, the knowledge about antibiotics as well as the risk of antibiotic resistance is fairly good and homogeneous. Only one-fifth of respondents was convinced that antibiotics cure common

appropriate use of antibiotics is also associated with other common behaviour patterns, such as failure to complete the recommended treatment or self-medication. Self-medication with antimicrobials almost always involves unnecessary, inadequate, and ill-timed dosing, creating an ideal environment for microbes to adapt rather than be eliminated. Self-medication with antimicrobials is common in many areas of world, particularly in developing countries with loose regulatory systems where antibiotics are sold over the counter drugs, but also in some affluent countries. A higher prevalence of self-medication with antibiotics was reported in South Europe (19%) in comparison with northern Europe (3%) and central Europe (6%). In some countries of Africa, 100% of antimicrobial use is without prescription and in Asia it reaches 58%.

Mechanisms of AMR and microbes involved

Natural selection, antibiotic overuse and misuse, insufficient access to safe water and sanitation, and substandard and counterfeit drugs are a few causes of AMR. Antibiotic overuse and misuse include but are not limited to incomplete treatment, inappropriate prescription, and self-medication. Bacteria that survive a partial antibiotic course may acquire resistance. Additionally, prescribing medicines for viral infections, self-prescribing, or utilizing leftover antibiotics without medical supervision can contribute to AMR. Insufficient sanitation and poor hygiene practices contribute to the proliferation of infectious diseases, resulting in heightened reliance on antibiotics and subsequent development of resistance. Finally, low-quality medications may not have enough active substances or the correct dose, resulting in insufficient therapy and the development of resistance. Microorganisms have developed various and ingenious strategies to withstand the antibacterial effects of previously effective medications in treating illnesses. These systems enable microorganisms to endure attacks from antibiotics and other antimicrobial chemicals that often hinder their development or cause their complete demise. Bacteria and other parasites demonstrate remarkable adaptive mechanisms by making structural modifications and employing strategic metabolic pathways, enabling them to disregard or neutralize antimicrobial substances that pose a threat. Typical resistance mechanisms involve enzymatic modification or degradation of antibiotics, limiting the entry of antibiotics into cells to prevent their build-up, alterations to metabolic pathways, modifying binding sites like ribosomes to reduce drug effectiveness, and increasing the activity of efflux pumps that remove antibiotics from cells before they can reach adequate levels. Bacteria may also create biofilms, surface-bound communities with varying nutrition levels and limited antibiotic penetration.

Artificial intelligence in combating AMR

Currently, artificial intelligence is used in various healthcare fields, demonstrating its broad implementation in modern medical procedure. Several studies that have been published on artificial intelligence demonstrate its effectiveness in combating antimicrobial resistance by rapidly identifying

patterns in bacterial behavior and optimizing treatment strategies accordingly these advancements hold great promise for the development of more effective and personalized approaches in addressing the global health threat posed by antimicrobial-resistant pathogens. The emergence of artificial intelligence (AI) and machine learning approaches presents promising opportunities to strengthen antimicrobial stewardship and precision medicine strategies addressing the pressing crisis of AMR. As AMR undermines the efficacy of standard antibiotic regimens against increasingly pervasive “superbugs”, AI tools able to enhance diagnostics, optimize prescribing patterns, and replenish depleted drug pipelines will become invaluable. Within healthcare delivery, AI integration constitutes an evolutionary step building upon traditional antibiotic stewardship programs reliant on specialized staff oversight and formulary restriction policies. Advanced neural networks and predictive analytics may identify positive cultures or high-probability infections earlier based on clinical presentations, allowing faster targeted therapy. Similarly, AI prescription assistants can integrate hospital metadata on local microbiology, individual patient factors, and treatment guidelines to recommend optimal antibiotic selection.

Such AI antibiotic advisors limit empirical overuse of broad agents. As human clinicians often excessively prescribe antibiotics in the absence of definitive diagnostics, intelligent safeguards balancing infection risks versus resistance generation can prove invaluable. AI integration may also expand stewardship programs’ capacity for continuous patient monitoring on appropriate antibiotic discontinuation post-cultures. Outside direct care, AI-powered epidemiology surveillance detecting local resistance outbreaks can better inform dynamic formulary policies. Computational approaches mining -omics datasets, published literature, and molecular libraries may also reveal novel drug targets or chemical scaffolds for antibiotic development pipelines increasingly abandoned by pharmaceutical companies. Overall, AI stewardship augmenting traditional antimicrobial governance and precision medicine efforts constitute a key evolutionary step toward preserving antibiotic efficacy.

A number of limitations still constrain contemporary artificial intelligence’s ability to combat AMR, centered on data quality, algorithmic biases, and real-world implementation barriers. Most healthcare AI remain narrow artificial neural networks trained on limited clinical datasets vulnerable to inherent biases. Careless application risks exacerbating antimicrobial overuse and toxicities if inaccurate predictions erode clinician trust or introduce new usage drivers. The majority of antibiotic prescription data also originates from developed nations, risking reduced model generalizability. Furthermore, most AI antibiotic advisors still lack sufficient transparency and explainability of underlying logic for clinician users. Gain of user trust requires explainable models so recommendations considered can be clinically validated based on available metadata. On the drug development end, despite successes in scaffold prediction or mechanism elucidations, experimental validation remains quite sparse. Beyond technical limitations, the majority of AI antimicrobial tools still remain confined to academic research without clear translation pathways toward clinical and policy integration. Still, with prudent development and application, AI constitutes a promising avenue amidst the pressing AMR crisis. Challenges in addressing AMR

Tackling the emergence of AMR presents complex challenges with no facile resolutions. Efforts to reduce humanity’s vast utilization of antimicrobials are obstructed by their widespread integration into medical care and food animal production economics. Lacking rapid point-of-care diagnostics, physicians often depend on empiric antibiotic prescribing to safeguard against bacterial infections, while modern farming systems predicate the regular administration of antimicrobials to livestock for infection prevention and growth promotion. Implementation of antimicrobial stewardship programs in healthcare and updated animal husbandry policies lag considerably despite awareness of resistance risks associated with antibiotic

overuse. Compounding these issues, the antibiotic drug development pipeline cannot keep pace with the continuous evolution of MDR pathogens. Pharmaceutical companies increasingly abandon costly antimicrobial research with limited profit incentives. And while policy expansions financing antibiotic development mark progress, near-term solutions seem unlikely considering phase trial durations.

Further frustrating containment efforts, international coordination on AMR surveillance and stewardship guidelines remains piecemeal despite organizations like the WHO, CDC, and UN recognizing its borderless risks. Variable access to quality diagnostics and antibiotic oversight across countries enables local emergence and global spread of novel resistance factors. Patches of weak stewardship may continually undermine and negate localized progress. Ultimately, the unique ‘tragedy of the commons’ nature of antibiotic resistance demands equitable, cooperative global action and shared responsibility. However, geopolitical complexities continue obstructing consensus on binding international policies and funding channels needed to strengthen antimicrobial stewardship and innovation worldwide.

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