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Antibiotic resistance as a global challenge to modern medicine: scale, mechanisms and countermeasure strategies

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Introduction: Almost a century ago, the discovery of antimicrobials radically changed the course of modern medicine. Previously fatal infections—pneumonia, sepsis, tuberculosis—became treatable, and surgical interventions became safe. However, today, these advances are under threat. Antibiotic resistance (AMR) represents one of the most serious threats to global public health, characterized by the World Health Organization as an already-emerging "silent pandemic" capable of reversing the medical advances of the 20th century.

Epidemiological scale of the threat

According to global burden of disease estimates, approximately 5 million deaths were associated with bacterial antibiotic resistance in 2019, with nearly 1.3 million deaths directly attributable to infections caused by drug-resistant strains. Predictive models indicate a further deterioration of the situation: by 2050, the annual number of deaths directly attributable to AMR could reach 2 million.

The spread of resistance among common infections is particularly alarming. Global data from the GLASS (Global Antimicrobial Resistance and Surveillance System) show that one in six bacterial infections worldwide is currently resistant to standard antibiotics. Between 2018 and 2023, resistance increased in more than 40% of monitored pathogen-antibiotic combinations, with an average annual increase of 5% to 15%.

Significant regional disparities exacerbate the problem. The highest rates of resistance are found in countries in Southeast Asia and the Eastern Mediterranean, where approximately one in three bacterial infections is resistant to standard treatment. In the African region, this figure is approximately 20%. The situation is particularly concerning in sub-Saharan Africa, where, without decisive action, up to 4.1 million AMR-related deaths are projected to occur annually by 2050.

Mechanisms of resistance formation

Antibiotic resistance develops as a result of a complex interaction of microbiological and socioeconomic factors. At the molecular level, bacterial resistance to antimicrobials is mediated through several key mechanisms, including enzymatic inactivation of antibiotics (e.g., β-lactamases), altered targets of action (mutations in PBPs and ribosomal proteins), decreased cell wall permeability, activation of efflux pumps, and modification of metabolic pathways.

Horizontal gene transfer mediated by plasmids, transposons, and integrons plays a key role in the spread of resistance genes. Studies show the widespread distribution of plasmid-borne resistance determinants, such as the blaCTX-M (third-generation cephalosporin), blaKPC (carbapenem), and mcr (colistin) genes, among clinical isolates of Escherichia coli and Klebsiella pneumoniae in various

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countries. The high contamination of the environment, livestock products, and food products with resistance genes confirms the importance of the transmissible route for the spread of resistant strains.

Driving factors of the AMR pandemic

Experts identify a complex set of interconnected factors contributing to the global spread of resistance. First and foremost, this is the irrational use of antibiotics in human, veterinary, and agricultural medicine. Self-medication, unnecessary prescriptions, and incomplete courses of antibiotic therapy are common in low- and middle-income countries, creating selective pressure on bacterial populations. In the agricultural sector, antibiotics are widely used not only for therapeutic purposes but also as growth promoters and prophylactic agents in livestock farming and aquaculture.

Secondary drivers include urbanization, population growth, inadequate healthcare infrastructure, and ineffective regulatory policies. Conflicts and humanitarian crises create a "perfect storm" for the spread of resistance: the destruction of healthcare systems, disruption of supply chains, unsanitary living conditions, and lack of laboratory diagnostics create an environment in which resistance develops and spreads at maximum speed.

Priority pathogens and clinical challenges

Gram-negative bacteria, particularly E. coli and K. pneumoniae, pose the greatest threat. According to global surveillance data, over 40% of E. coli isolates and 55% of K. pneumoniae isolates are resistant to third-generation cephalosporins, the standard first-line therapy. In some African countries, resistance rates to these drugs exceed 70%. Of particular concern is the growing resistance to carbapenems, the "last-line" antibiotics that remain the only treatment option for infections caused by extended-spectrum β-lactamase producers.

An equally significant problem is the resistance of Neisseria gonorrhoeae. Reports of gonococcal strains resistant to both ceftriaxone and azithromycin, recorded in the UK in 2018, indicate the potential for completely untreatable sexually transmitted infections. Outbreaks of extensively resistant Salmonella typhi in Pakistan, which were treatable with only one remaining antibiotic, illustrate the reality of a "post-antibiotic era."

Global Countermeasures Strategies

In response to the growing threat, the international community is intensifying efforts to contain AMR. In 2024, the UN General Assembly adopted the Political Declaration on AMR, which aims to reduce mortality from infections caused by resistant bacteria by 10% by 2030. In May 2026, the World Health Assembly approved the updated Global Action Plan on AMR for 2026–2036, which defines a comprehensive, multisectoral strategy within the One Health framework, integrating human, animal, and environmental health.

Key areas of counteraction include:

- strengthening epidemiological surveillance systems through the Global Surveillance System on Antimicrobial Resistance (GLASS-AMR);
- implementation of programs for the rational use of antibiotics (antimicrobial stewardship) with the AWaRe (Access, Watch, Reserve) classification;
- strengthening infection control and prevention, including vaccination programs and improved water supply and sanitation;
- stimulating innovation in the development of new antibiotics, rapid diagnostic tests and alternative therapies, including the use of artificial intelligence to discover new drugs;

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- Ensuring equitable access to quality antibiotics, diagnostics and vaccines, especially in fragile and conflict-affected areas.

Conclusion

Antibiotic resistance is a systemic challenge that requires coordinated action at all levels—from global policy to local clinical practice. Successful response depends on the ability to integrate AMR control strategies into healthcare systems, ensure sustainable funding, strengthen international collaboration, and develop innovative approaches to diagnosing and treating infections. As WHO experts emphasize, delays in taking action will have devastating consequences, increasing morbidity, length of hospital stays, healthcare costs, and leading to millions of preventable deaths. With resistance spreading faster than new antibiotics can be developed, time has become a critical resource in the fight against this "silent pandemic."