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ANTIMICROBIAL RESISTANCE: MECHANISM, CHALLENGES, IMPACTS AND FUTURE PROSPECTS

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ABSTRACT

Antimicrobial resistance (AMR) represents a significant global health crisis, primarily fueled by the misuse and overuse of antibiotics across various sectors, resulting in the emergence of resistant microorganisms. The origins of AMR can be traced back to the introduction of penicillin, with the rise of multidrug-resistant pathogens presenting major challenges to healthcare systems globally. The inappropriate use of antibiotics in human medicine, veterinary practices, and agriculture fosters the proliferation of resistance genes, creating what has been termed a "Silent Pandemic" that could outpace other mortality causes by 2050.

AMR impacts both human and animal health, complicating the treatment of infections caused by resistant pathogens. Various mechanisms, including enzymatic alteration and biofilm development, allow microbes to resist the effects of antibiotics. The dwindling availability of effective antibiotics endangers routine medical procedures and could result in millions of fatalities annually if not addressed.

The economic repercussions of AMR are significant, with estimated losses reaching trillions of dollars, imposing substantial financial strains on healthcare systems and agriculture. Researchers are exploring the potential of artificial intelligence to combat AMR by enhancing diagnostics and treatment approaches; however, challenges related to data quality and algorithmic bias remain.

To tackle AMR effectively, a One Health strategy is essential, incorporating considerations of human, animal, and environmental influences. This approach entails improving surveillance systems, promoting stewardship initiatives, and investing in research and development for novel antimicrobial agents. Public education, awareness campaigns, and international cooperation are vital for combating AMR and ensuring the continued effectiveness of antibiotics for future generations.

Keywords: Resistance to antibiotic drug , strategies for prevention, alternative therapies , one health approach.

1. INTRODUCTION

Antimicrobial resistance (AMR) has surfaced as one of the most urgent global health challenges of the 21st century[1]. AMR occurs when microorganisms, including bacteria, fungi, parasites, and viruses, evolve and become resistant to antimicrobial drugs, such as antibiotics, which are typically used to treat infections[2]. This growing problem is largely the result of the overuse or improper use of antibiotics across various sectors, particularly in healthcare, agriculture, animal health, conflict zones, and food production[3]. Frequently referred to as the "Silent Pandemic," AMR demands immediate and effective action rather than being seen as an issue for the distant future. Without preventive strategies, it is projected that by 2050, AMR could surpass all other causes of death worldwide. In 2019, it was estimated that more than 1.2 million deaths were directly attributed to AMR globally, and this number is expected to rise to approximately 10 million deaths per year by 2050 if effective measures are not taken to combat the issue[4].

This study aims to thoroughly examine antimicrobial resistance by outlining its historical development, explaining the mechanisms behind it, and evaluating its significant impact on both human and animal populations. It will also analyze historical and current prevalence trends, predict future challenges, explore the potential role of artificial intelligence in addressing AMR, highlight key obstacles, and offer recommendations for effective mitigation strategies and further research[5].

History of Antimicrobial Resistance :

The issue of antimicrobial resistance (AMR) poses a significant threat to global public health and is increasingly recognized as a critical concern worldwide. AMR refers to the capacity of microorganisms, such as bacteria, viruses, fungi, and parasites, to resist the action of drugs that were previously successful in treating infections. This resistance undermines the effectiveness of antibiotics, antivirals, and other medications, leading to increased rates of illness, death, and healthcare costs. Tackling AMR has become a top global health priority, requiring immediate and coordinated efforts from

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governments, healthcare professionals, researchers, and the public. AMR arises when microorganisms such as bacteria, viruses, fungi, and parasites develop resistance to antimicrobial drugs, rendering standard treatments ineffective and raising the risk of infection. While the development of resistance is a natural process, human actions have greatly accelerated its progression in recent decades[6].

Microbes are driven to develop resistance when antimicrobial agents are misused or overused in medical, veterinary, and agricultural contexts, leading to selective pressure that favors survival and the acquisition of adaptive mutations or resistance genes[7]. This enables these organisms to thrive in environments where antibiotics and antiseptics once eliminated them. Bacteria and other microbes are highly adaptable, capable of mutating quickly and transferring resistance genes through horizontal gene transfer, allowing them to develop multiple resistance mechanisms. Microorganisms that acquire AMR make it more difficult to treat human and animal diseases, prolong illness, increase the risk of infection spread, lengthen hospital stays, necessitate more expensive treatments, and raise mortality rates[8]. The increasing cycle of resistance is not only a current concern but is rooted in the long history of antimicrobial use.

The history of AMR dates back to Alexander Fleming's discovery of penicillin in 1928 and the m ass production and widespread use of antibiotics in the 1940s. However, resistance to these appeared almost immediately. The first documented cases of penicillin-resistant Staphylococcus drugs aureus were reported in 1942, and tetracycline resistance followed in 1953.The extensive use of antibiotics in agriculture during the 1950s and 1960s further accelerated resistance. Methicillin-resistant Staphylococcus aureus (MRSA) emerged in 1961, followed by resistance to multiple classes of antibiotics. By the 1980s, multidrug-resistant (MDR) tuberculosis had become a global epidemic, and in the 1990s, gram-negative bacteria such as Escherichia coli and Klebsiella pneumoniae developed extended-spectrum beta-lactamase (ESBL) resistance. The rise of multidrug resistance reduced the availability of effective antibiotics and led to pharmaceutical companies withdrawing from antibiotic research. This combination of growing resistance and a lack of new drug development continues to burden healthcare systems. We are now facing a post-antibiotic era in which common infections and minor injuries could once again become deadly. Without urgent solutions, millions of lives may be lost to AMR-related infections annually[9].

Antimicrobial Resistance Impact on Human Beings and Animals :

AMR has emerged as a complex issue affecting the health of both humans and animals. The overuse and misuse of antibiotics in various sectors, including healthcare, agriculture, and veterinary medicine, have accelerated the rise of drug-resistant strains of microorganisms. The heavy reliance on antibiotics has led to the development of antibiotic-resistant bacteria, often referred to as superbugs, which create significant challenges in treatment effectiveness and can cause severe infections. Moreover, the slow progress in developing new antimicrobial drugs worsens the problem, as resistance evolves more quickly than new effective treatments are discovered[10].

AMR has become one of the most serious threats to human health in the 21st century. Infections that were once treatable are becoming increasingly difficult to manage, presenting substantial clinical challenges[11]. The loss of effective first-line antimicrobials has led to an increased dependence on second- and third-line treatments, which tend to be more expensive, more toxic, and require longer treatment courses. Extended illnesses strain both individual and healthcare system resources due to prolonged hospital stays. Longer recovery periods also negatively affect economic productivity by increasing time away from work. AMR infections also result in more frequent outpatient visits, laboratory tests, and the need for isolation measures[12]. The mortality directly attributed to AMR pathogens is responsible for over a million deaths annually. Without effective antibiotics, routine procedures such as surgeries, organ transplants, chemotherapy, and neonatal care could become significantly more dangerous due to the inability to control infections. Some pathogens, referred to as "ESKAPE" bacteria—resistant forms of Enterococcus faecium, Staphylococcus aureus, Klebsiella pneumoniae, Acinetobacter baumannii, Pseudomonas aeruginosa, and Enterobacter species—are among the most challenging MDR threats hospitals face today. In a post-antibiotic era, even minor injuries or common infections could prove fatal[13].

AMR poses a risk not only to human health but also to food production, as it enables the transfer of resistant zoonotic pathogens from animals to humans. The overuse of antibiotics in livestock for disease treatment and growth promotion has created reservoirs of resistance[14] . This increases the transmission risk of MDR bacteria like Salmonella and Campylobacter through the food chain or via contact with animal handlers. Resistant bacterial strains easily spread between species. Wildlife can also acquire AMR from environmental exposure, contributing to further pathogen transmission. Resistant microbes contaminate the broader environment through fertilizers made from manure, affecting waterways and produce that ultimately reach consumers. These microbes can also exchange AMR genes with normal environmental and human-associated

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microflora[15] . Limited treatment options for resistant infections in animals can lead to outbreaks among cattle, poultry, and sheep, often necessitating culling and causing significant economic losses while threatening food supplies. Estimates suggest that AMR could lead to a financial impact of $3–4 billion in the livestock sector alone in the coming decades. The detrimental effects of resistance across agriculture and economic systems also have disruptive ripple effects on national security and trade. Therefore, a comprehensive One Health approach, integrating human, animal, and environmental health monitoring and interventions, is crucial to fully addressing the significant and potential negative impacts of AMR on animals, which in turn increase human exposure risks[16].

Mechanisms of Antimicrobial Resistance:

Natural selection, excessive and improper use of antibiotics, lack of access to clean water and sanitation, and the availability of substandard or counterfeit medications are some of the contributing factors to antimicrobial resistance (AMR). Misuse and overuse of antibiotics encompass actions such as incomplete courses of treatment, incorrect prescriptions, and self-medication[17]. When bacteria survive an incomplete course of antibiotics, they may develop resistance. Additionally, prescribing antibiotics for viral infections, self-prescribing, or using leftover antibiotics without professional guidance can accelerate the development of AMR. Inadequate sanitation and poor hygiene practices foster the spread of infectious diseases, leading to increased dependence on antibiotics, which in turn promotes resistance[18]. Lastly, low-quality drugs may contain insufficient active ingredients or incorrect dosages, leading to ineffective treatment and the emergence of resistance Microorganisms have evolved various sophisticated mechanisms to resist the effects of antibiotics that were once effective in treating infections.

These mechanisms allow them to survive attacks from antibiotics and other antimicrobial agents that are designed to either inhibit their growth or kill them. Bacteria and other microorganisms exhibit remarkable adaptability by altering their structures and employing specific metabolic pathways that enable them to evade or neutralize antimicrobial agents[19].

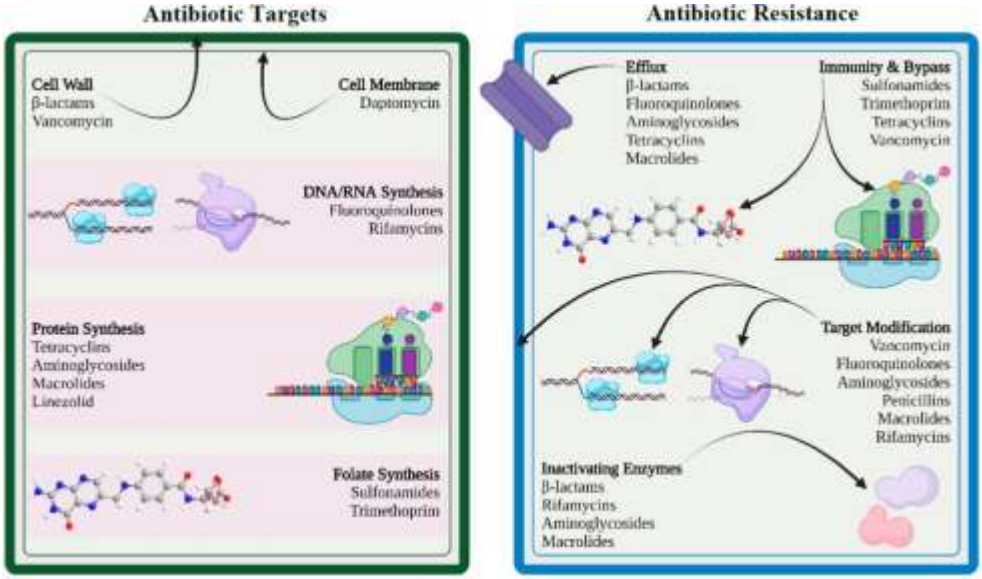

Figure No.1: Antibiotic Targets and Mechanisms of Drug Resistance .

Common resistance mechanisms include enzymatic alteration or destruction of antibiotics, limiting antibiotic entry into cells to prevent accumulation, modifications to metabolic pathways, altering target sites such as ribosomes to reduce the efficacy of the drug, and enhancing the activity of efflux pumps that expel antibiotics from the cells before they can reach effective concentrations. Bacteria can also form biofilms, which are surface-bound communities with varying nutrient levels and limited antibiotic penetration. These biofilms provide an additional layer of protection for the bacteria[20] . Moreover, bacteria are highly skilled at acquiring resistance genes from neighboring cells or even different species through horizontal gene transfer, which is facilitated by plasmids and other mobile genetic elements . These acquired genes often contain multiple complex resistance mechanisms within a single unit, allowing the rapid spread of multidrug resistance (MDR) across microbial populations[21.] The ability to efficiently transfer genetic material horizontally provides microorganisms with a wide range of resistance strategies that they can adapt to survive against the continuous development and use of antimicrobial treatments in medicine.

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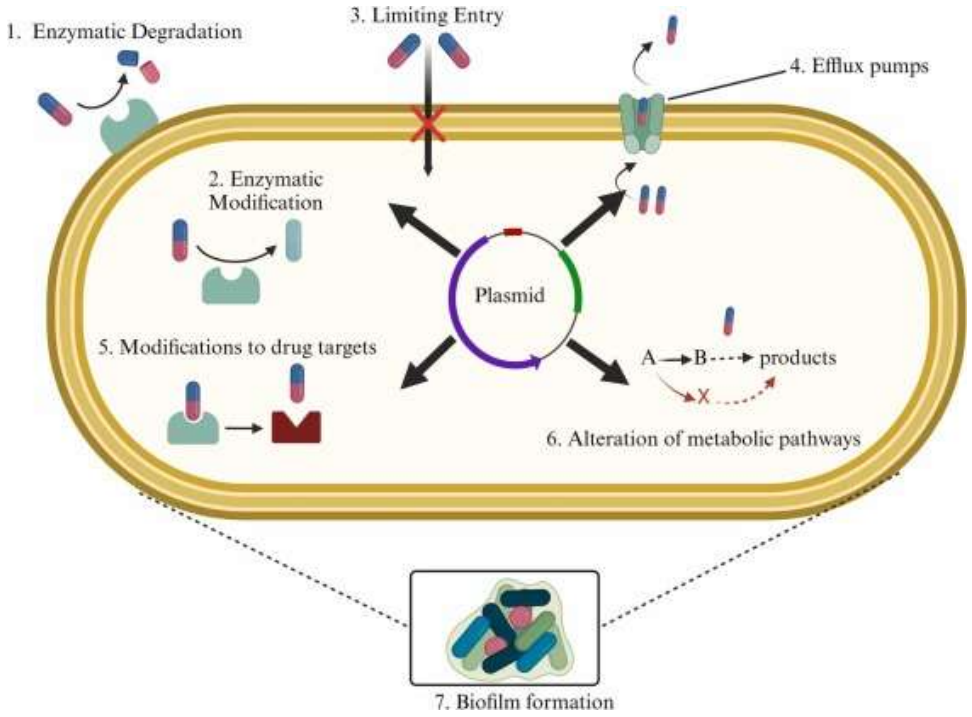

Figure No.2: Mechanisms of Antimicrobial Resistance in Bacteria.

Over the past few decades, numerous microorganisms have developed antimicrobial resistance (AMR) through various mechanisms. Methicillin-resistant Staphylococcus aureus (MRSA) has acquired resistance to multiple antibiotics, including methicillin, due to mutations in the mecA and mecC genes, as well as horizontal gene transfer. Carbapenem-resistant Enterobacteriaceae, such as Klebsiella pneumoniae and Escherichia coli, have gained resistance to carbapenem antibiotics by acquiring carbapenemase-producing genes. These genes are often located on plasmids, enabling their spread among different bacterial species. Extended-spectrum beta-lactamase (ESBL)-producing E. coli has developed resistance to a wide range of antibiotics, including penicillins and cephalosporins, by acquiring ESBL genes, frequently via plasmids. Mutations in the DNA of multidrug-resistant (MDR) Mycobacterium tuberculosis have made them resistant to numerous anti-tuberculosis drugs. Acinetobacter baumannii has become resistant to several antibiotics through a combination of mutations and the acquisition of resistance genes[22]. Multidrug-resistant Neisseria gonorrhoeae has emerged, making it resistant to front-line antibiotics used to treat gonorrhea. Fluconazole-resistant Candida species, responsible for opportunistic oral and genital infections, have posed a significant challenge to high-risk populations. Additionally, viral infections like HIV and influenza frequently develop resistance mutations to existing antiviral treatments. The rapid increase of these MDR microbial strains highlights the ability of pathogenic bacteria, viruses, fungi, and protozoa to swiftly adapt and evade chemical agents designed to eliminate them[23].

Historical and Current Occurrence of Antimicrobial Resistance:

The initial cases of antibiotic resistance were observed shortly after penicillin became widely used. This period marked the start of an ongoing struggle against the evolving resistance of bacteria. By the mid-20th century, the rise of MRSA and other resistant pathogens highlighted a growing public health issue. The situation worsened due to the indiscriminate use of antibiotics in agriculture and livestock, which facilitated the dissemination of resistance genes. This trend clearly indicated that increased antibiotic usage led to greater resistance, necessitating a constant development of new antimicrobials. In North America, the annual incidence of infections related to antibiotic resistance exceeded 2 million cases, resulting in approximately 23,000 deaths. In Europe, over 700,000 infections developed resistance to antibiotics, contributing to more than 33,000 deaths each year. Moreover, the economic impact of these infections is estimated to exceed €1.5 billion. Notably, between 2000 and 2010, antibiotic use surged by 36%, while around 20% of global mortality is currently attributed to infectious diseases. The situation further deteriorated with the emergence of nosocomial infections, which became a significant cause of morbidity and mortality, leading to extended hospital stays and increased healthcare costs. Presently, more than 15% of nosocomial infections are linked to multidrug-resistant organisms, some of which have no effective treatment options[24].

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According to the 2019 Antibiotic Resistance Threats Report by the Centers for Disease Control and Prevention (CDC), the United States reports over 2.8 million antibiotic-resistant infections annually, resulting in more than 35,000 deaths. In India, child mortality due to bacterial infections resistant to antibiotics occurs every nine minutes, with over 50,000 infants at risk of dying from sepsis caused by antibiotic-resistant microorganisms, rendering standard treatments ineffective. Findings from the European Antimicrobial Resistance Surveillance Network (EARS-Net) study conducted from 2015 to 2019 indicated variations in the prevalence of antimicrobial resistance across the European Union, depending on bacterial species, drug classes, and geographic locations. Key microorganisms investigated in this report included Escherichia coli (44.2%), Staphylococcus aureus (20.6%), Klebsiella pneumoniae (11.3%), Enterococcus faecalis (6.8%), Pseudomonas aeruginosa (5.6%), Streptococcus pneumoniae (5.3%), Enterococcus faecium (4.5%), and Acinetobacter spp. (1.7%).

MRSA is responsible for approximately 13–74% of Staphylococcus aureus infections globally, impacting around 119,247 individuals in the United States and resulting in 19,832 deaths. The latest Global Antimicrobial Surveillance System (GLASS) report from the World Health Organization (WHO) highlights significant antimicrobial resistance among 500,000 individuals diagnosed with bacterial infections across 22 countries. The most commonly identified resistant bacterial strains include Escherichia coli, Staphylococcus aureus, Streptococcus pneumoniae, and Klebsiella pneumoniae. The prevalence of resistance to ciprofloxacin, a frequently prescribed antibiotic for urinary tract infections, varies widely among countries, with resistance rates for Escherichia coli ranging from 8.4% to 92.9%, and for Klebsiella pneumoniae from 4.1% to 79.4%. Penicillin resistance has been reported as high as 51% among countries participating in GLASS. In 2019, data on MRSA bloodstream infections were collected from 25 nations, regions, and zones, while data on Escherichia coli bloodstream infections were obtained from 49 countries. A study by Kraker et al. reported a median prevalence of MRSA at 12.11%, with an interquartile range (IQR) of 6.4–26.4%. Additionally, the median resistance rate of E. coli to third-generation cephalosporins was found to be 36%, with an IQR of 15.2-63%[25].

Future Impact of Antimicrobial Resistance and Related Challenges:

The future outlook appears grim, as indicated by research commissioned by the UK government. This study forecasts that by 2050, antibiotic-resistant illnesses could cause around 10 million deaths each year. Simple infections and minor injuries may once again pose life-threatening risks, while major medical procedures such as organ transplants, chemotherapy, or hip replacements could become exceedingly perilous. The economic impact of AMR is projected to reach $100 trillion USD by 2050 [26]. Low- and middle-income countries are likely to bear the heaviest burden, as the increase in bacterial resistance outpaces the development of new antimicrobial treatments, and limited resources hinder access to existing high-cost therapies.

There is a critical lack of global coordination, with fragmented containment efforts unable to keep pace with the adaptive capacity of pathogenic bacteria continually exposed to extensive antimicrobial use in healthcare, agriculture, and the environment. In addition to the direct mortality and economic consequences, the diminishing effectiveness of antimicrobials could severely hinder modern medicine and allow for the resurgence of previously rare bacterial infections. Populations such as cancer patients, immunocompromised individuals, and those undergoing surgical procedures are particularly vulnerable to new extensively or pan-drug-resistant bacterial strains[27]. Furthermore, the overall burden of common infectious diseases, including pneumonia, tuberculosis, and gastrointestinal infections, could significantly increase in a post-antibiotic world. Ultimately, the rapid loss of effective antimicrobial options threatens decades of medical advancements and suggests a return to a time when bacterial infections were major threats to public health[28].

The Role of Artificial Intelligence in Addressing Antimicrobial Resistance:

Artificial intelligence is currently utilized across various healthcare domains, showcasing its extensive application in modern medical practices. Numerous studies highlight the effectiveness of AI in addressing antimicrobial resistance by swiftly recognizing patterns in bacterial behavior and optimizing treatment strategies accordingly .These advancements promise the development of more effective and personalized methods to tackle the global health challenge posed by antimicrobial-resistant pathogens. The advent of AI and machine learning technologies presents significant opportunities to enhance antimicrobial stewardship and precision medicine in response to the urgent crisis of AMR. As antimicrobial resistance undermines the effectiveness of standard antibiotic treatments against increasingly prevalent “superbugs”, AI tools capable of improving diagnostics, refining prescribing practices, and revitalizing depleted drug pipelines will become indispensable[29].

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In healthcare delivery, integrating AI represents an evolution of traditional antibiotic stewardship programs that rely on specialized staff oversight and formulary restrictions. Advanced neural networks and predictive analytics can detect positive cultures or high-probability infections more swiftly based on clinical presentations, enabling quicker targeted therapies[30]. Similarly, AI-driven prescription assistants can utilize hospital metadata regarding local microbiology, individual patient characteristics, and treatment guidelines to recommend optimal antibiotic choices. These AI antibiotic advisors help minimize the empirical overuse of broad-spectrum agents. Given that human clinicians often prescribe antibiotics excessively in the absence of definitive diagnostics, intelligent safeguards that balance infection risks with the potential for resistance can be invaluable. AI integration may also enhance stewardship programs' capacity for continuous patient monitoring, guiding appropriate antibiotic discontinuation after cultures are obtained[31]. Beyond direct care, AI-powered epidemiological surveillance can identify local resistance outbreaks, informing adaptive formulary policies. Computational methods that analyze -omics datasets, published research, and molecular libraries may also uncover novel drug targets or chemical frameworks for antibiotic development pipelines, which pharmaceutical companies increasingly abandon. Overall, AI-enhanced stewardship, alongside traditional antimicrobial governance and precision medicine efforts, represents a critical evolutionary advancement in preserving antibiotic effectiveness.

However, several limitations currently hinder AI's capacity to combat AMR, primarily related to data quality, algorithmic biases, and barriers to real-world implementation. Most healthcare AI systems consist of narrow artificial neural networks trained on limited clinical datasets that are susceptible to biases. Improper application may worsen antimicrobial overuse and toxicity if inaccurate predictions undermine clinician trust or create new drivers for usage. Additionally, the majority of antibiotic prescription data originates from developed countries, which may limit the generalizability of models. Furthermore, many AI antibiotic advisors lack sufficient transparency and explain ability regarding their underlying logic for clinician users. Building user trust necessitates explainable models so that recommendations can be clinically validated based on available metadata. On the drug development side, despite successes in scaffold prediction or elucidating mechanisms, experimental validation remains scarce. Moreover, most AI antimicrobial tools are still confined to academic research with unclear pathways for clinical and policy integration. Nevertheless, with careful development and application, AI offers a promising avenue in the face of the pressing AMR crisis[31-32].

Difficulties in Controlling Antimicrobial Resistance:

Addressing the emergence of antimicrobial resistance (AMR) involves intricate difficulties that lack straightforward solutions. Efforts to curb the extensive use of antimicrobials in society face hindrances due to their deep-rooted presence in medical practices and the economic frameworks of food animal production. Without rapid point-of-care diagnostics, healthcare providers often rely on empirical antibiotic prescribing to protect against bacterial infections. Meanwhile, modern agricultural systems routinely require the administration of antimicrobials to livestock for infection prevention and growth enhancement[33] .Although there is awareness of the risks associated with antibiotic overuse, the implementation of antimicrobial stewardship programs in healthcare and updated animal husbandry regulations has lagged significantly[34]

Moreover, the antibiotic development pipeline struggles to keep up with the ongoing evolution of multidrug-resistant (MDR) pathogens. Pharmaceutical companies are increasingly abandoning the costly research required for antimicrobial development due to limited profit incentives. While policy initiatives aimed at funding antibiotic development signify progress, immediate solutions appear unlikely given the lengthy durations of clinical trials[35]. Compounding these containment efforts, international coordination on AMR surveillance and stewardship guidelines remains fragmented, despite the recognition of its cross-border risks by organizations such as the WHO, CDC, and UN. Inconsistent access to quality diagnostics and antibiotic regulation across different countries allows for the local emergence and global dissemination of novel resistance factors[36]. Areas with weak stewardship may consistently undermine and negate localized advancements. Ultimately, the unique 'tragedy of the commons' aspect of antibiotic resistance necessitates equitable and collaborative global action alongside shared responsibility. However, geopolitical complexities continue to hinder consensus on binding international policies and funding mechanisms essential for enhancing antimicrobial stewardship and innovation on a global scale[37]. AMR transcends geographical limitations and poses a global threat to populations. Recently, previously manageable infections have transformed into major health challenges. The lack of effective antimicrobial agents increases the risks associated with routine medical procedures, including surgeries, chemotherapy, and organ transplants. Beyond the detrimental effects on human health, AMR also presents significant economic burdens for healthcare systems, governments, and society as a whole[38]. The financial strain associated with managing resistant infections is substantially increased due to prolonged hospital stays, heightened healthcare consultations, and the need for expensive last-resort medications[39].

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Suggestion for Investigation:

Mitigating antimicrobial resistance (AMR) requires a comprehensive approach that integrates multiple sectors and engages various stakeholders. First and foremost, there is a need for Enhanced surveillance systems to accurately monitor and track the emergence and spread of resistant pathogens. Additionally, it is essential to stress the importance of using antimicrobials responsibly to reduce the selective pressure that fosters resistance development[40]. Promoting antimicrobial stewardship programs within healthcare settings, along with enforcing regulations on antibiotic use in agriculture and veterinary practices, can effectively decrease the overuse of these medications

Research focused on actionable strategies is vital for developing and implementing effective measures to combat AMR. Initiatives should investigate the complex interplay of factors contributing to the emergence of resistance. Key areas of study include antimicrobial prescribing practices, usage trends in agriculture, the role of horizontal gene transfer in resistance propagation, and the socio-cultural influences on antimicrobial consumption. Understanding the dynamics of microbial ecosystems, such as the resistome and environmental factors, is critical for devising comprehensive strategies[41].

Encouraging interdisciplinary collaboration among microbiologists, pharmacologists, epidemiologists, social scientists, and policymakers is essential to enhance our understanding of antimicrobial resistance. The development of new antimicrobial agents and alternative therapies is a key component in addressing antibiotic resistance, alongside research in surveillance and diagnostics[42]. Innovations in drug development—such as identifying novel molecular targets, optimizing existing antibiotics, and exploring non-traditional treatment options like bacteriophage therapy and immunomodulation—are crucial in this arena. Promoting translational research is vital to accelerate the application of new interventions, bridging laboratory findings with clinical practice. Collaboration among academia, pharmaceutical companies, and regulatory bodies is critical to expedite the discovery, evaluation, and approval of new antimicrobial agents[43].

Moreover, it is vital to strengthen research and development efforts to discover novel antibiotics and investigate alternative therapeutic approaches. Collaborative initiatives among governments, pharmaceutical firms, and research institutions are necessary to incentivize and streamline the development of innovative antimicrobial agents[44].Additionally, metal nanoparticles have emerged as a potential therapeutic strategy for addressing AMR. The application of artificial intelligence may also play a significant role in tackling the rising rates of AMR. Furthermore, the concurrent use of antibiotics with ant virulence drugs may enhance the management of pathogenic microorganisms while minimizing the risk of developing resistance Finally, it is imperative to allocate resources towards advancing vaccines and diagnostics to reduce dependence on antimicrobial agents and enable precise therapeutic interventions[45].

Essential Priorities for Public Health Measures:

Enhancing public awareness and education is crucial for addressing antimicrobial resistance (AMR). It is vital to equip the general population with thorough knowledge about the appropriate use of antibiotics, the negative consequences of their overuse, and the importance of following prescribed treatment protocols. Healthcare professionals must stay updated on antimicrobial stewardship, as well as infection prevention and control measures. In hospital environments, antibiotic stewardship involves developing guidelines, providing education to healthcare staff, and implementing protocols to ensure the responsible use of antibiotics. In outpatient settings, antibiotic stewardship focuses on educating patients, conducting diagnostic tests, and advocating for antibiotic prescriptions only when necessary. By fostering a culture of responsible antimicrobial use, we can reduce the selection pressure on microorganisms and thereby slow the advancement of antimicrobial resistance[46].Various alternative strategies for tackling antimicrobial resistance are as following :

- **Antibiotic Stewardship:** Prudent use of antibiotics, administering them only when essential and at the correct dosage. Safeguards antibiotic efficacy, limits the development of resistance. Demands shifts in behavior from healthcare providers and patients. Calls for behavioral adjustments in both healthcare providers and patients. Tracking adherence is crucial.
- **New Antibiotic Development:** Innovation and development of new antibiotics focusing on unique bacterial pathways. Combats resistance to current medications. Significant expense, prolonged development timeline, and risk of cross-resistance.
- **Combination Therapy:** Utilizing a combination of antibiotics with distinct mechanisms of action to combat infections. Synergy can boost efficacy and minimize resistance. Complicated dosing schedules, higher likelihood of side effects. Intricate dosing protocols, heightened risk of adverse effects, and possibility of antagonism.

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- **Phage Therapy:** Employing bacteriophages (viruses that attack bacteria) to specifically target certain bacterial strains. Precisely focused strategy, which can be quickly modified. Insufficient understanding of phage-bacteria dynamics, regulatory hurdles, and inconsistent efficacy.
- **Beneficial Microbes And Dietary Fibers:** Stimulating the development of beneficial bacteria to dominate over pathogenic strains Promotes a balanced microbial community, limiting room for harmful organisms. Limited knowledge of optimal strains, challenges in colonization and persistence.
- **Immunotherapy:** Enhancing the development of beneficial microbes to outcompete detrimental strains. Broad range of targets, potential for sustained protection. Limited to particular infections, possibility of risk. Focused on particular infections, potential for autoimmunity, and challenging development.
- **Reusing Establishing Medicine:** Discovering non-antibiotic medications with antimicrobial activity. Quicker development, potentially reduced expenses. Few available options, risk of unintended effects, and need for dose adjustment.
- **Alternatives To Antibiotics:** Creating non-antibiotic therapies, such as antimicrobial peptides, bacteriocins, or metal nanoparticles. Lower risk of resistance and varied mechanisms of action. Scarce clinical evidence, risk of toxicity, and challenges in delivery.
- **Public Instruction And Awareness Efforts:** Encouraging appropriate hygiene, responsible antibiotic use, and awareness of resistance. Lowers unnecessary demand for antibiotics and their misuse. Behavioral change occurs gradually, is difficult to quantify, and necessitates continuous efforts.
- **Data Collection System:** Observing and analyzing resistance trends to inform treatment protocols. Delivers real-time information to guide treatment choices. Requires significant resources and faces challenges in data sharing and standardization.
- **Environmental Regulations:** Minimizing antibiotic application in agriculture and industry to curb the spread of resistance. Alleviates selection pressure for resistance development. Requires regulatory enforcement, international collaboration, and economic considerations.
- **One Health Approach :** Integrating efforts in human, animal, and environmental health to address resistance. Handles the complex origins of resistance proliferation. Requires collaboration among disciplines, facing challenges in communication and policy coordination.

Global cooperation is essential in tackling the widespread issue of antimicrobial resistance (AMR). Governments, international organizations, and key stakeholders must work together to align regulations, share best practices, and coordinate efforts to effectively combat AMR. Initiatives like GLASS help promote data sharing and improve the global response to AMR. The exchange of knowledge, resources, and experiences can lead to the development of comprehensive strategies to address AMR on a global scale. The general agreement among scientists and healthcare experts is that AMR poses a significant and urgent global health challenge. However, within the scientific community, there are a few differing viewpoints or debates on specific aspects of the issue[47].

These perspectives do not necessarily deny the problem but offer alternative views on certain elements or propose different methods for addressing it[48]. There are ongoing discussions and varying opinions on various aspects of AMR, including the impact of environmental factors on its development, the potential of alternative therapies like bacteriophages, the importance of ensuring equitable access to vital antibiotics, and the implementation of measures to curb unnecessary antibiotic use[49]. For example, bacteriophage therapy has proven effective in treating antibiotic-resistant Acinetobacter baumannii infections. Another case is Clostridium difficile, an AMR bacterium that has been treated with monoclonal antibodies like bezlotoxumab[50].

2. CONCLUSION

The ability of bacteria and other microbes to swiftly evolve resistance jeopardizes a cornerstone of modern medicine—effective antimicrobial treatments. Humanity's excessive use of antibiotics in both healthcare and agriculture has exerted significant evolutionary pressure, allowing harmful bacteria to develop various strategies that render once-powerful antimicrobials ineffective. With antibiotic discovery lagging behind the rapid spread of multidrug resistance across the globe, we now face the grim reality of a post-antibiotic era. Establishing stewardship programs to minimize inappropriate antibiotic use and enhancing infection control are critical initial measures.

However, the distinctive "tragedy of the commons" nature of antimicrobial resistance, which transcends national borders and sectors, calls for binding, collective action on a global scale. By implementing coordinated surveillance, equitable access, conservation policies, and increased investment in innovation through a One Health framework, we can reduce the spread of resistance and safeguard the effectiveness of antimicrobials. Continued delays could lead to a regression toward the pre-antibiotic era, where infectious diseases once again dominate mortality rates, posing a serious threat to modern medical practices and global health security.

Abbreviations:

AMR, Antimicrobial Resistance; MRSA, Methicillin-Resistant staphylococcus aureus; MDR, Multidrug Resistant; ESBL, Extended-Spectrum beta lactamase; HIV, Human Immuno Deficiency Virus; CDC, Centers for Disease Control and Prevention; WHO, world Health Organization; IQR, Interquartile Range; UK, United Kingdom of Great Britain and Northern Ireland; USD, United State Dollars; AI, Artificial intelligence; UN, United Nation.

3. REFERENCES

[1] Williams-Nguyen, J.; Sallach, J.B.; Bartelt-Hunt, S.;.Antibiotics and Antibiotic Resistance in Agroecosystems: State of the Science. J. Environ. Qual. 2016, 45, 394–406.

[2] Tenover, F.C. Mechanisms of antimicrobial resistance in bacteria. Am. J. Med. 2006, 119, S3–S10; discussion S62–S70.

[3] Zhou, G.; Shi, Q.S.; Huang, X.M.; Xie, X.B. The Three Bacterial Lines of Defense against Antimicrobial Agents. Int. J. Mol. Sci.2015, 16, 21711–21733.

[4] Khameneh, B.; Diab, R.; Ghazvini, K.; Fazly Bazzaz, B.S. Breakthroughs in bacterial resistance mechanisms and the potential ways to combat them. Microb. Pathog. 2016, 95, 32–42.

[5] Read, A.F.; Woods, R.J. Antibiotic resistance management. Evol. Med. Public Health 2014, 2014, 147.

[6] George, A. Antimicrobial resistance, trade, food safety and security. One Health 2018, 5, 6–8.

[7] Samreen; Ahmad, I.; Malak, H.A.; Abulreesh, H.H. Environmental antimicrobial resistance and its drivers: A potential threat to public health. J. Glob. Antimicrob. Resist. 2021, 27, 101–111.

[8] ARC. Global burden of bacterial antimicrobial resistance in 2019: A systematic analysis. Lancet 2022, 399, 629–655.

[9] Ghimpet,eanu, O.M.; Pogurschi, E.N.; Popa, D.C.; Dragomir, N.; Drăgotoiu, T.; Mihai, O.D.; Petcu, C.D. Antibiotic Use in Livestock and Residues in Food-A Public Health Threat: A Review. Foods 2022, 11, 1430.

[10] Levy, S.B.; Marshall, B. Antibacterial resistance worldwide: Causes, challenges and responses. Nat. Med. 2004, 10, S122–S129.

[11] 11.nHutchings, M.I.; Truman, A.W.; Wilkinson, B. Antibiotics: Past, present and future. Curr. Opin. Microbiol. 2019, 51, 72–80.

[12] Iskandar, K.; Murugaiyan, J.; Hammoudi Halat, D.; Hage, S.E.; Chibabhai, V.; Adukkadukkam, S.; Roques, C.; Molinier, L.;Salameh, P.; Van Dongen, M. Antibiotic Discovery and Resistance: The Chase and the Race. Antibiotics 2022, 11, 182.

[13] Uddin, T.M.; Chakraborty, A.J.; Khusro, A.; Zidan, B.R.M.; Mitra, S.; Emran, T.B.; Dhama, K.; Ripon, M.K.H.; Gajdács, M.;Sahibzada, M.U.K.; et al. Antibiotic resistance in microbes: History, mechanisms, therapeutic strategies and future prospects. J.Infect. Public Health 2021, 14, 1750–1766.

[14] Suay-García, B.; Pérez-Gracia, M.T. Present and Future of Carbapenem-resistant Enterobacteriaceae (CRE) Infections. Antibiotics2019, 8, 122.

[15] Kaur, N.; Prasad, R.; Varma, A. Prevalence and antibiotic susceptibility pattern of methicillin resistant staphylococcus aureus in tertiary care hospitals. Biotechnol. J. Int. 2014, 4, 228–235.

[16] Parmanik, A.; Das, S.; Kar, B.; Bose, A.; Dwivedi, G.R.; Pandey, M.M. Current Treatment Strategies Against Multidrug-Resistant Bacteria: A Review. Curr. Microbiol. 2022, 79, 388.

[17] Davies, J.; Davies, D. Origins and evolution of antibiotic resistance. Microbiol. Mol. Biol. Rev. MMBR 2010, 74, 417–433.

[18] Koch, N.; Islam, N.F.; Sonowal, S.; Prasad, R.; Sarma, H. Environmental antibiotics and resistance genes as emerging contaminants: Methods of detection and bioremediation. Curr. Res. Microb. Sci. 2021, 2, 100027.

[19] Lee, J.H. Perspectives towards antibiotic resistance: From molecules to population. J. Microbiol. 2019, 57, 181–184.

[20] Martinez, J.L. General principles of antibiotic resistance in bacteria. Drug Discov. Today. Technol. 2014, 11, 33–39.
[21] Cox, G.; Wright, G.D. Intrinsic antibiotic resistance: Mechanisms, origins, challenges and solutions. Int. J. Med. Microbiol. IJMM2013, 303, 287–292.
[22] Holmes, A.H.; Moore, L.S.; Sundsfjord, A.; Steinbakk, M.; Regmi, S.; Karkey, A.; Guerin, P.J.; Piddock, L.J. Understanding the mechanisms and drivers of antimicrobial resistance. Lancet 2016, 387, 176.
[23] Fernández, L.; Hancock, R.E. Adaptive and mutational resistance: Role of porins and efflux pumps in drug resistance. Clin.Microbiol. Rev. 2012, 25, 661–681.
[24] Rizi, K.S.; Ghazvini, K.; Noghondar, M.K. Adaptive antibiotic resistance: Overview and perspectives. J. Infect. Dis. Ther. 2018, 6, 363.
[25] Godijk, N.G.; Bootsma, M.C.J.; Bonten, M.J.M. Transmission routes of antibiotic resistant bacteria: A systematic review. BMCInfect. Dis. 2022, 22, 482.
[26] da Costa, P.M.; Loureiro, L.; Matos, A.J. Transfer of multidrug-resistant bacteria between intermingled ecological niches: The interface between humans, animals and the environment. Int. J. Environ. Res. Public Health 2013, 10, 278–294.
[27] Landers, T.F.; Cohen, B.; Wittum, T.E.; Larson, E.L. A review of antibiotic use in food animals: Perspective, policy, and potential. Public Health Rep. 2012, 127, 4–22.
[28] Chancey, S.T.; Zähner, D.; Stephens, D.S. Acquired inducible antimicrobial resistance in Gram-positive bacteria. Future Microbiol.2012, 7, 959–978.
[29] Reygaert, W.C. An overview of the antimicrobial resistance mechanisms of bacteria. AIMS Microbiol. 2018, 4, 482–501.
[30] Choi, U.; Lee, C.R. Distinct Roles of Outer Membrane Porins in Antibiotic Resistance and Membrane Integrity in Escherichia coli.Front. Microbiol. 2019, 10, 953.
[31] Ghai, I.; Ghai, S. Understanding antibiotic resistance via outer membrane permeability. Infect. Drug Resist. 2018, 11, 523–530.
[32] Dutt, Y.; Dhiman, R.; Singh, T.; Vibhuti, A.; Gupta, A.; Pandey, R.P.; Raj, V.S.; Chang, C.M.; Priyadarshini, A. The Association between Biofilm Formation and Antimicrobial Resistance with Possible Ingenious Bio-Remedial Approaches. Antibiotics 2022,11, 930.
[33] Van Acker, H.; Van Dijck, P.; Coenye, T. Molecular mechanisms of antimicrobial tolerance and resistance in bacterial and fungal biofilms. Trends Microbiol. 2014, 22, 326–333.
[34] Saha, M.; Sarkar, A. Review on Multiple Facets of Drug Resistance: A Rising Challenge in the 21st Century. J. Xenobiotics 2021, 11,197–214.
[35] Foster, T.J. Antibiotic resistance in Staphylococcus aureus. Current status and future prospects. FEMS Microbiol. Rev. 2017, 41,430–449.
[36] Wendlandt, S.; Shen, J.; Kadlec, K.; Wang, Y.; Li, B.; Zhang, W.J.; Feßler, A.T.; Wu, C.; Schwarz, S. Multidrug resistance genes in staphylococci from animals that confer resistance to critically and highly important antimicrobial agents in human medicine. Trends Microbiol. 2015, 23, 44–54.
[37] Blair, J.M.; Webber, M.A.; Baylay, A.J.; Ogbolu, D.O.; Piddock, L.J. Molecular mechanisms of antibiotic resistance. Nat. Reviews.Microbiol. 2015, 13, 42–51.
[38] Nikaido, H.; Pagès, J.M. Broad-specificity efflux pumps and their role in multidrug resistance of Gram-negative bacteria. FEMSMicrobiol. Rev. 2012, 36, 340–363.
[39] Poole, K. Efflux-mediated antimicrobial resistance. J. Antimicrob. Chemother. 2005, 56, 20–51.
[40] Blair, J.M.; Richmond, G.E.; Piddock, L.J. Multidrug efflux pumps in Gram-negative bacteria and their role in antibiotic resistance. Future Microbiol. 2014, 9, 1165–1177.
[41] Abushaheen, M.A.; Muzaheed; Fatani, A.J.; Alosaimi, M.; Mansy, W.; George, M.; Acharya, S.; Rathod, S.; Divakar, D.D.; Jhugroo,C.; et al. Antimicrobial resistance, mechanisms and its clinical significance. Dis. A-Mon. DM 2020, 66, 100971.
[42] Chaw, P.S.; Höpner, J.; Mikolajczyk, R. The knowledge, attitude and practice of health practitioners towards antibiotic prescribing and resistance in developing countries-A systematic review. J. Clin. Pharm. Ther. 2018, 43, 606–613.

[43] Chokshi, A.; Sifri, Z.; Cennimo, D.; Horng, H. Global Contributors to Antibiotic Resistance. J. Glob. Infect. Dis. 2019, 11, 36–42.

[44] Klein, E.Y.; Van Boeckel, T.P.; Martinez, E.M.; Pant, S.; Gandra, S.; Levin, S.A.; Goossens, H.; Laxminarayan, R. Global increase and geographic convergence in antibiotic consumption between 2000 and 2015. Proc. Natl. Acad. Sci. USA 2018, 115, E3463–E3470.

[45] Van Boeckel, T.P.; Brower, C.; Gilbert, M.; Grenfell, B.T.; Levin, S.A.; Robinson, T.P.; Teillant, A.; Laxminarayan, R. Global trends in antimicrobial use in food animals. Proc. Natl. Acad. Sci. USA 2015, 112, 5649–5654.

[46] Castro-Sánchez, E.; Moore, L.S.; Husson, F.; Holmes, A.H. What are the factors driving antimicrobial resistance? Perspectives from a public event in London, England. BMC Infect. Dis. 2016, 16, 465.

[47] Arcilla, M.S.; van Hattem, J.M.; Haverkate, M.R.; Bootsma, M.C.J.; van Genderen, P.J.J.; Goorhuis, A.; Molhoek, N.; Schultsz, C.; et al. Import and spread of extended-spectrum β-lactamase-producing Enterobacteriaceae by international travelers (COMBAT study): A prospective, multicenter cohort study. Lancet. Infect. Dis. 2017, 17, 78–85.

[48] McCubbin, K.D.; Anholt, R.M.; de Jong, E.; Ida, J.A.; Nóbrega, D.B.; Kastelic, J.P.; Conly, J.M.; Götte, M.; McAllister, T.A.; Orsel, K.;et al. Knowledge Gaps in the Understanding of Antimicrobial Resistance In Canada. Front. Public Health 2021, 9, 726484.

[49] Lin, T.Z.; Jayasvasti, I.; Tiraphat, S.; Pengpid, S.; Jayasvasti, M.; Borriharn, P. The Predictors Influencing the Rational Use of Antibiotics Among Public Sector: A Community-Based Survey in Thailand. Drug Healthc. Patient Saf. 2022, 14, 27–36.

[50] Brives, C.; Pourraz, J. Phage therapy as a potential solution in the fight against AMR: Obstacles and possible futures. PalgraveCommun. 2020, 6, 100.