



International Journal of Innovative Research in Science Engineering and Technology (IJIRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.699

Volume 15, Special Issue 1, January 2026

Review Article: Combating Antimicrobial Resistance: Emerging Strategies and Innovations

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ABSTRACT: The widespread increase in antimicrobial resistance is being linked to an increase in fatalities due to overuse of antimicrobial drugs. AMR is causing a pandemic that is unnoticed and affects both animals and humans. AMR occurs when viruses, bacteria, fungi, and parasite evolve, rendering drugs ineffective over time. Antimicrobial use should be rationalized, new antimicrobial drugs should be researched and developed, public awareness should be raised, hand hygiene should be better, and alternative treatments such as bacteriophages should be regulated. AI is changing the fight against antimicrobial resistance (AMR) by making it easier to find patterns of resistance early on and by helping to guide based precision on therapy of antimicrobial. AI helps to develop innovative and targeted approaches to overcome resistant pathogens by combining it with novel strategies like phage therapy, antimicrobial peptides, nano antibiotics, CRISPR-based therapeutics, and immunotherapy. Combating and protecting the antimicrobial drug efficacy is crucial, also prevent the emergence and spread of the resistance of antimicrobial for future generations.

KEYWORDS: Antimicrobial resistance, Multiple drug-resistant pathogens, Phage therapy, Nanotechnology, CRISPR.

I. INTRODUCTION

Antimicrobial resistance (AMR) has emerged as a grave global threat, undermining centuries of medical progress and transforming previously treatable infections into severe conditions. It is a major driver of increased illness, death, and healthcare expenditure worldwide—currently responsible of nearly 700,000 fatalities yearly, a figure projected to rise to about 10 million deaths by 2050 per year. In the year 2014, the WHO identified AMR as the top ten health threats of global, a designation that still holds nearly a decade later. [1] The principle outcome of AMR is the declining effectiveness of drugs, making infections increasingly difficult to treat as well as raising the risk of disease transmission, serious illness, and death. AMR manifests in diverse forms and magnitudes. Data from the US reveal around cases of 2 million infections caused by bacterial resistant yearly, leading to an addition of \$20 billion in cost of healthcare. [2]

The issue of antibiotics' over and rampant misuse in health care, agricultural and livestock settings has fuel the development and spread of resistant pathogens which in turn we see play out in increased mortality, morbidity and economic instability. We study the performance of international as well as national AMR action plans which include the World Health Organization's Global Action Plan (WHO-GAP), U.S. National Action Plan for Combatting Antibiotic-Resistant Bacteria, and also the European One Health Action Plan for AMR. [3]

Addressing these problems calls for innovative approaches going beyond conventional antimicrobial treatment. The Additional development of rapid diagnostic tools, AI-driven clinical decision-making, and globally cohesive One Health approaches are critical for preventing the spread of antimicrobial resistance. [4]

II. LITERATURE SEARCH STRATEGY

A literature search was conducted across PubMed, Scopus, Web of Science, ScienceDirect, and Google Scholar to find studies published between 2014 and 2025. Following the PRISMA framework, the search used Boolean operators to

combine key terms like “Antimicrobial resistance,” “CRISPR,” “Strategies and innovation,” and “Drug Resistant Pathogens.” We only included peer-reviewed primary research and systematic reviews published in English that specifically looked at CRISPR-based innovations as a treatment or diagnostic method for multidrug-resistant bacteria. On the other hand, editorials, conference abstracts, grey literature, papers published before 2014, and those that concentrated on non-antimicrobial of CRISPR technology's uses were not included in the study. This stringent screening procedure guarantees that the review summarizes the most recent and technically significant developments in the international efforts to reduce drug-resistant pathogens with the help of antimicrobial resistance studies.

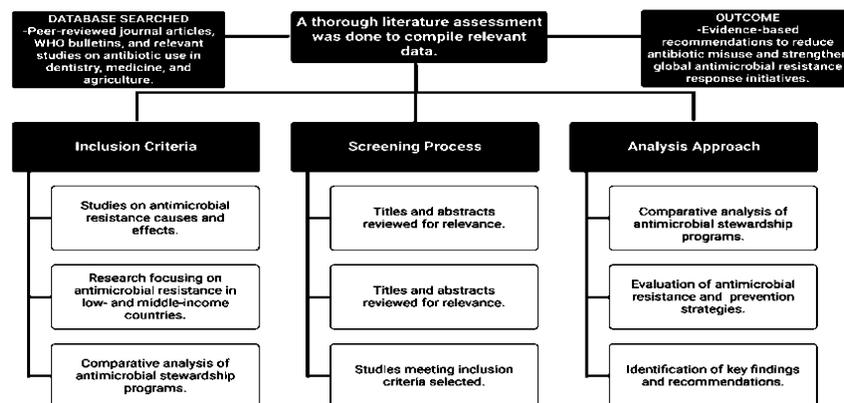


Fig1: Navigating Antimicrobials and Combating Antimicrobial Resistance:

III. MECHANISMS FOR ANTIMICROBIAL RESISTANCE (AMR)

Mechanism	Underlying Process	Representative Example(s)	Predominant in / Key Notes
 1. Enzymatic Drug Inactivation	Bacterial enzymes degrade, modify, or neutralize antibiotics before reaching their target.	β-lactamases hydrolyzing β -lactam antibiotics (penicillins, cephalosporins). Aminoglycoside-modifying enzymes (acetyl-, adenylyl-, phosphoryl-transferases).	 Common in Gram-negative bacteria . Major mechanism in penicillin & cephalosporin resistance .
 2. Target Site Modification	Structural alteration of the drug-binding site reduces affinity, preventing antibiotic action.	• Altered PBP2a in <i>MRSA</i> → methicillin resistance. • DNA gyrase/topoisomerase IV mutations → fluoroquinolone resistance.	 Prominent in Gram-positive cocci (e.g., <i>Staphylococcus</i> , <i>Enterococcus</i>).
 3. Decreased Permeability & Active Efflux	Outer membrane porin loss reduces entry; efflux pumps actively expel antibiotics from the cell.	Efflux pumps (AcrAB-TolC, MexAB-OprM systems). Porin mutation in <i>Pseudomonas aeruginosa</i> .	 Widespread in Gram-negative pathogens ; major cause of multidrug resistance (MDR) . [5]
 4. Metabolic Bypass Mechanisms	Bacteria develop alternative enzymes or pathways unaffected by the antibiotic target.	Resistant dihydrofolate reductase → Trimethoprim resistance. Alternative PABA synthesis pathways .	 Enables survival despite enzyme inhibition; common in folate pathway inhibitors .
 5. Biofilm Formation	Bacterial communities form a protective extracellular matrix limiting antibiotic penetration and immune clearance.	<i>Pseudomonas spp.</i> , <i>Staphylococcus epidermidis</i> , <i>E. coli</i> biofilms.	 Found in chronic wounds, implants, catheters ; high tolerance to multiple antibiotics.
 6. Target	Proteins bind to antibiotic targets,	Tet(M) protects ribosomal	 Seen in Gram-positive

Mechanism	Underlying Process	Representative Example(s)	Predominant in / Key Notes
Protection Proteins	shielding them without altering structure or function.	binding sites from tetracycline. Qnr proteins protect DNA gyrase from quinolones.	cocci and enteric bacteria.
⚡ 7. Genetic Transfer of Resistance	Horizontal gene transfer spreads resistance genes across species via mobile elements.	Plasmids, transposons, integrons, and bacteriophages.	🌐 Accelerates global dissemination of resistance; core driver of AMR evolution.

IV. STRATEGIES OF AMR

A key strategy to curb the emergence of antimicrobial resistance (AMR) involves strengthening infection prevention measures such as proper hygiene, routine screen of risk patients, isolation of individuals infected with organisms, also promoting the appropriate use of kits for personal protection. It is projected that by 2050, AMR could account for as many as 10 million deaths each year and generate a worldwide economic loss of approximately USD 100 trillion. The capacity of organisms to withstand antimicrobial agents designed to destroy them contribute to huge rates of disease, death, medical expenses, representing a major issue to global health of public.[3]



GLOBAL: Addressing antimicrobial resistance (AMR) demands joint action steps from multiple investors, including healthcare providers, policymakers, and general public. In this global effort at large we put forth Antimicrobial Stewardship Programs (ASPs) and Infection Prevention and Control (IPC) as very important components which play a large role in what we do to reduce resistant spread.[2,6]

1. **Combat Resistance: Antimicrobial Stewardship Strategies:**Antimicrobial Stewardship Programs (ASPs) encourage the judicious use of antibiotics to maintain their effectiveness, enhance patient outcomes, and lower healthcare expenses.[2]
2. **IPC for AMR: A Global Strategy for a Safer Future:** Infection Prevention and Control (IPC) measures play a vital role not only in reducing but also in actively combating antimicrobial resistance (AMR). This modern approach offers multiple advantages, including environmental sustainability through reduced water consumption, better infection management, and greater comfort for patients.[7] Complementary innovations,such as the use of electrolyzed water and automated “no-touch” disinfection technologies-like ultraviolet-C light systems-represent valuable components of a comprehensive AMR control strategy’These methods are very important as many of the pathogens related to ICU settings may remain. [8]
3. **B. NATIONAL:** Although antibiotic resistance is a worldwide concern, the primary efforts to tackle this challenge must be implemented at national and local levels. In The WHO also outlines clear guidance on the structure and functioning of national AMR committees, emphasizing the importance of enforcing legal prescription requirements for antibiotics, adopting standardized treatment protocols for infectious diseases, maintaining essential drug lists, and monitoring implementation through policy indicators.[7]
4. **National committee Establishment:** Monitoring resistance patterns of antibiotics and ensuring intersectoral coordination is crucial. Other necessary strategies include the enforcement of standard treatment guidelines, maintenance of an EDL, and improvement of immunization coverage. Introduced in 2011, the National Policy for the AMR Containment aims to study the emergence, spread, and causes of resistance, establish antimicrobial programs, promote rational drug use, and support innovation for new and effective antimicrobials.[8]

National Action Plan on Antimicrobial Resistance (NAP-AMR) of India: It outlines the current status of resistant containment in India and the strategies planned to tackle the issue. Launched in April 2017 by the Ministry of Health and Family Welfare, it is aligned with the WHO Action Plan on AMR (2015) and follows the approach of One Health, acknowledging the link between human and animal and also the environmental health.

Objectives of the NAP-AMR: The key goals of the National Action Plan (2017–2021) are to: Improve awareness and AMR understanding through targeted communication, training and education. Generate knowledge and evidence through comprehensive surveillance of antimicrobial use and resistance from human, animal, food, and of environmental sectors. Encourage researches and innovation for the development of new diagnostics, drugs, vaccines, and alternative treatments. Ensure strong leadership and intersectoral collaboration at national and international levels.[9]

C.LOCAL: Infectious diseases, globally, are a serious cause of morbidity and mortality; this holds true especially for those countries that have limited access to health care. reported in a review on community antibiotic misuse that over one-third of patients did not follow their prescribed antibiotic regimens, and one-quarter retained leftover antibiotics for future use, reflecting poor adherence to proper antibiotic practices. The use of alcohol contained hand rubs, regular handwashing been shown to effectively prevent infections, thereby limiting the spread of antimicrobial resistance.[8]

V. TECHNOLOGICAL AND SCIENTIFIC INNOVATIONS FOR AMR CONTROL

The introduction of antibiotics since the 1940s has greatly improved both human and animal health. This issue emerged as bacteria developed genes that confer resistance to antibiotic residues. These resistance genes enable infections to persist under various conditions, limiting treatment options and increasing morbidity and mortality by allowing resistant bacterial populations to thrive in humans and animals. Antimicrobial resistance is a severe threat to health worldwide, reducing the efficacy of antibiotics and making the treatment of infectious diseases more difficult.

1. VACCINES: Vaccines stimulate the immune system to identify and reply to disease-causing pathogens, saving millions of lives annually. They also lower the incidence of diseases requiring differential diagnosis, easing the pressure on diagnostic services and enabling more efficient allocation of resources for surveillance and management. This systems are critical for tracking AMR trends, guiding targeted vaccination, and measures as well as guidelines.[10]

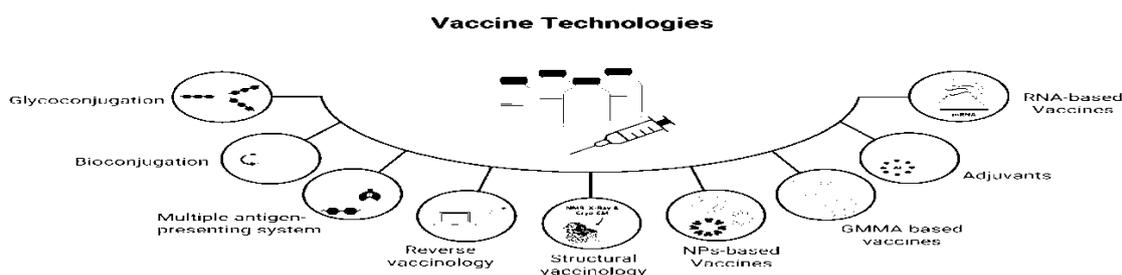


Fig2: Innovative technologies available and can accelerate the development of vaccines against pathogens.

Despite their benefits, vaccine development faces challenges due to bacterial genetic diversity, multiple potential antigens, and the ability to cause variable infections depending on host conditions. Multicomponent vaccines are often employed to target several antigens, broadening coverage and preventing resistance arising from mutations. However, identifying conserved and immunogenic antigens is difficult. Therefore, designing vaccines to combat AMR requires careful consideration of both host and pathogen factors. Determining the target population and understanding the protective immune responses within that population are essential for effective vaccine development.[11]

2. PHAGE THERAPY: Despite several obstacles, using bacteriophages—viruses that specifically destroy certain bacteria—remains an attractive option. In parts of Eastern Europe, particularly Georgia, phage therapy has been applied

clinically since the early 20th century to manage bacterial infections. With rising global antibiotic resistance, interest in this approach is growing.

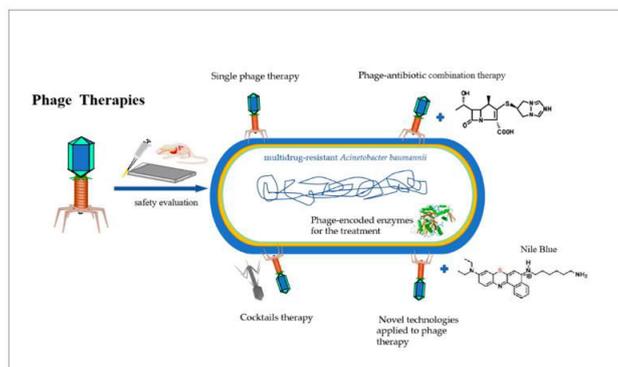


Fig 3: Mechanism of action of bacteriophages

Bacteriophages combat bacterial infections by attaching to specific bacterial receptors, injecting DNA or RNA, also the replicating inside the host, ultimately causing the lysis of bacteria and new phage release. Phage's can also act synergistically with antibiotics, improving bacterial eradication, limiting resistance development, and preserving beneficial microbiota. Regulatory challenges remain, as phage therapy is commonly used in specialized centres in Eastern Europe but is still experimental and strictly controlled in Western nations.[12]

1. Laboratories and the Therapeutic Practices

1. Isolation and Characterization of the Bacteriophages: Foundations of Therapeutic Applications.
2. In both research and clinical contexts, isolating and characterizing bacteriophages is essential to explore their biological functions and potential. By leveraging both lytic and lysogenic phage's, adaptable therapeutic approaches can be developed to combat bacterial infections and AMR, with ongoing research crucial to fully realize their potential as antibiotic alternatives.
3. Phage Therapy for Plant Agriculture;Antibiotic use in crop production has thus opened up the possibility of the evolution of resistant bacteria in the environment. Research, such as studies using phage ϕ XOF4 against *Xanthomonas oryzae* and phage cocktails targeting *Pectobacterium acrosticium*, has demonstrated substantial disease suppression and improved plant protection. Phage cocktails, combining multiple phages, provide broader host coverage and help counter bacterial diversity and resistance.
4. 1.3 Phage Therapy for Human Medicine and Veterinary:The One Health concept recognizes interconnectedness of human, environmental health, animal, emphasizing the mutual dependence. However, therapeutic outcomes may be limited by phage instability, immune system clearance, and suboptimal dosing in clinical studies. Approaches such as encapsulation, antacid-based formulations, and phage engineering are being investigated to improve stability and performance. Despite these challenges, clinical trials confirm phage safety and potential as sustainable solutions against antibiotic-resistant infections.[13]

3. NANOTECHNOLOGY: Nanotechnology in Antimicrobial Delivery and Targeting: The widespread occurrence of antibiotic resistance has become increasingly concerning in recent years, representing a major global public health threat as it results in millions of deaths worldwide. Engineered nanoparticles, like silver nanoparticles (Ag NPs), gold particles and liposomes, demonstrated enhanced delivery of drugs, eradication of biofilms, and targeted action against the multiple drug for resistant pathogens.[15,16]

Type of Nanoparticle	Targeting Pathogens	Mode of Action
Silver particles	Methicillin-resistant Staphylococcus aureus	Membrane disrupt integrity and ROS induce
Liposomes nanoparticles	E. coli	Enhance antibiotic delivery to biofilms
Gold particles	Pseudomonas aeruginosa	ROS generation and targeting the ligand

4. CRISPR-Cas SYSTEMS FOR PRECISION THERAPY: CRISPR-Cas technology has emerged as the revolutionary strategy against AMR, offering an unprecedented level of precision in targeting resistance-conferring genes. Out of 145 reviews, 19 specifically investigated the application and development of CRISPR-based antimicrobial approaches. With continued research, these strategies may become pivotal tools in combating global crisis of resistant infections.[17] CRISPR-Cas systems classification:

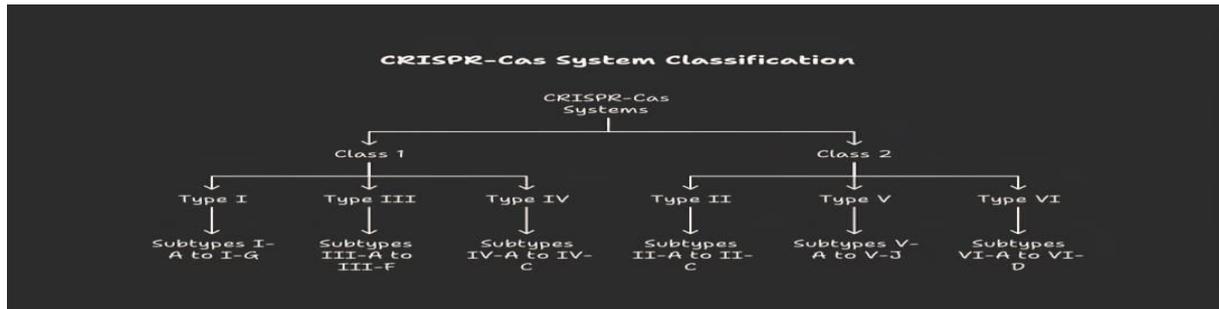


Fig 4: CRISPR-Cas System Classification

CRISPR-Cas systems in gene editing mechanism: The CRISPR-Cas defends for genetic elements in bacteria has three major stages: expression, adaptation and interference. In type III, crRNA associates with complexes to target DNA and RNA, with Cas7 and Csm6 executing cleavage. Type V relies on tracer RNA with Cas12b or Cas12c for interference, while type VI forms a Cas13-crRNA complex that targets single-stranded RNA, guided by a (PFS), analogous of a PAM.[18] CRISPR-Cas Detection in various genomes: With progress in bioinformatics, a wide range of computational tools has been developed to detect and analyse CRISPR-Cas systems. Direction, supports the prediction of CRISPR strand orientation. Notable examples include CRISPR-Local, Guide Scan, GPP sgRNA Designer, CRISPR SQL, and Off Scan. Integrating these detection, classification, and gRNA design tools into a single computational workflow could provide researchers with a fully automated, comprehensive platform for CRISPR-Cas system analysis, expanding their applications in genome editing and biotechnology. Antibiotic resistance eradication in bacteria: The CRISPR-Cas system can restore bacterial susceptibility to the antibiotics for targeting and deleting antibiotic resistance genes (ARGs) present on plasmids and chromosomes. Engineered CRISPR platforms can also prevent horizontal gene transfer of ARGs, confer immunity against resistance acquisition, and disrupt multidrug-resistant plasmids. Targeting essential genes or multiple loci further increases the system’s efficiency against complex resistance plasmids. Overall, CRISPR-Cas provides a precise and adaptable strategy for combating antimicrobial resistance and controlling the dissemination of drug-resistant pathogens.[18,20]

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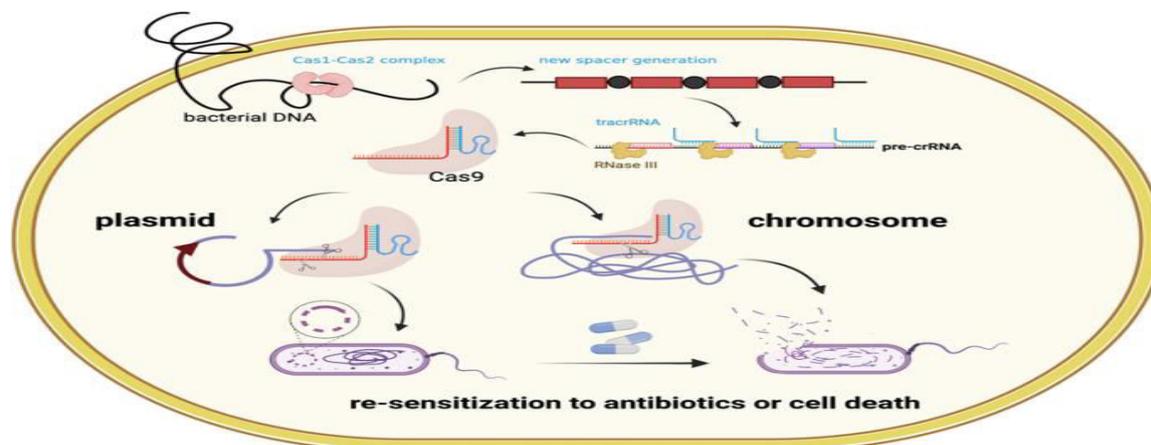


Fig 5: Use of CRISPR-Cas system against pathogenic bacteria

Delivery strategies: Nanoparticles provide a biocompatible, non-viral delivery platform with improved stability and targeted delivery. Conjugative and pheromone-responsive plasmids enable precise CRISPR transfer across bacterial populations. Despite their potential, these delivery approaches face limitations, including reduced efficiency, challenges in intracellular targeting, and concerns regarding long-term stability.[21,22]. Bacterial virulence: The system affects bacterial virulence by the acquisition and maintenance of virulence genes, often through interactions with phages and plasmids. In many bacterial species, an active CRISPR-Cas system restricts horizontal gene transfer, thereby reducing virulence, whereas its absence may increase pathogenic potential. Overall, CRISPR-Cas exerts a complex, species-dependent influence on virulence, and further investigation is necessary to elucidate its regulatory mechanisms and explore its potential for infection control.[23] Bacterial virulence: The system affects bacterial virulence by the acquisition and maintenance of virulence genes, often through interactions with phages and plasmids. In many bacterial species, an active CRISPR-Cas system restricts horizontal gene transfer, thereby reducing virulence, whereas its absence may increase pathogenic potential.[23]

5. IMMUNOTHERAPY FOR ENHANCED HOST RESISTANCE: Immunotherapy is not a new approach, but it has gained significant attention recently due to the identification of highly specific human polyclonal and monoclonal antibodies capable of targeting a wide array of biological sites. Active type of immunotherapy augments the immune system of patients to produce immune effectors, including the antibody and T cells, while passive type of immunotherapy includes the administration of immune components, such as antibodies or immune cells, generated *ex vivo*.[11]

6. PEPTIDES for anti-microbial (AMPs): AMPs are cationic host defence of peptides that are found in all biological kingdoms, from bacteria to fungi, plants, mammals, and protozoa. They exhibit their mode of action through several mechanisms. Instead of bacterial proteins, these molecules primarily interact with microbial membranes, which results in disrupting the bilayer structure. Finally, advances in sequencing and molecular dynamics enable the rapid modification and *in silico* production of these small peptides, allowing them to be used as adjuvants with other antibiotics, thereby enhancing efficacy and overcoming emerging resistance. [3Click or tap here to enter text.

7. COMBINATION THERAPIES AND PERSONALIZED MEDICINE: The growing problem of antimicrobial resistance (AMR) demands innovative approaches to managing infectious diseases. Together, these approaches improve treatment outcomes and provide effective tools against antimicrobial resistance. Employing microbial agents with distinct mode of action can further reduce cross-resistance and increase treatment success, particularly in infections caused by multidrug-resistant organisms.[25,26]. Employing microbial agents with distinct mode of action can further reduce cross-resistance and increase treatment success, particularly in infections caused by multidrug-resistant organisms.[26,28]

In contrast, personalized medicine emphasizes customizing treatment strategies to each patient's individual genetic, clinical, and environment characteristics. Precision antibiotic therapy, guided by pathogen-specific susceptibility data,

enables individualized treatment plans that maximize clinical effectiveness while limiting resistance emergence and reducing antibiotic-related complications.[25,27]

8. ANTIMICROBIAL PHOTODYNAMIC THERAPY:The increase of antimicrobial resistance (AMR) represents a significant global challenge of health, as it makes previously effective drugs ineffective against infectious microbes. This escalating resistance the pressing for the novel therapy approaches that tackle resistant of pathogens. In this, antimicrobial photodynamic therapy (aPDT) had a altern.

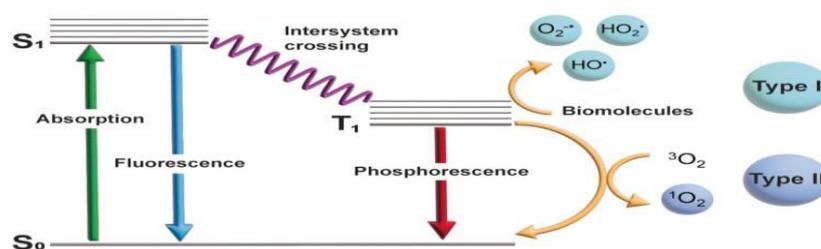


Fig 7: Jablonski diagram for the process of ROS in PDT.

9. PROBIOTICS AND POSTBIOTICS:Probiotics are among the products whose usage continues to rise each year, and they are available in a forms—mainly as food or dietary supplements (tablets, capsules, powders, ampoules), but also as medicinal products (pharmaco-biotics), and in certain cosmetic formulations. The World Health Organization defines probiotics as “live microorganisms” [2]. A probiotic formulation can contain a single microbial strain or a combination of multiple strains. The administration of probiotics is always strain-specific, and the benefits observed for one strain may not apply to another.[29].The development of a biofilm occurs in five stages: 1st initial attachment, 2nd the formation of microcolonies, 3rd maturation and 4th differentiation of biofilms, 5th detachment and dispersion. Growth of probiotic bacteria may suppress or inhibit the proliferation of pathogenic microbes. Beyond AAD, alleviating other intestinal and gastrointestinal disorders, including gastroenteritis, inflammatory bowel syndrome, and Helicobacter pylori infection. Certain strains, such as Weissella confusa, Bacillus subtilis, Lactobacillus acidophilus, Lactobacillus casei, and other yet-to-be-identified probiotics, have shown inhibitory effects against H. pylori.[30]

10. Artificial Intelligence the MACHINE LEARNING: In few years, intelligence (AI) has shown greater potential in managing antimicrobial resistance (AMR). AI-based sequencing applications have been utilized to investigate resistance mechanisms [12]. Development of antibiograms and personalized AMR prediction models using ML is a valued AI application for the detection of high-risk pathogens and susceptibility pattern analysis [9]. Following this approach, Yelling et al. investigated a ten-year dataset comprising more than 700,000 community-acquired UTIs and established a strong association between AMR and demographic factors, previous urine cultures, and previous antibiotic use. Their study resulted in an ML-based AMR prediction model identifying major UTI-causing pathogens and their resistance profiles.[31].Firstly, progress at the algorithmic level has produced a wide spectrum of learning methods, ranging from basic linear regression to advanced ensemble models and deep neural networks [9]. Such registries form valuable databases for developing robust and diverse datasets, enabling rapid advancement in AMR research and the creation of predictive prescription models. Continuous data recording will allow for the training and deployment of accurate ML algorithms to guide evidence-based prescribing decisions.[32]

VI. CHALLENGES AND LIMITATIONS

Antimicrobial resistance (AMR) represents a crucial issue of health in global arising from misuse of antibiotic, over-the-counter availability, excessive use in agriculture, and insufficient awareness and regulatory measures. Resistance evolves faster than the discovery of new drugs, while high development costs and low financial returns. Fragile healthcare infrastructures, inadequate diagnostic tools, and fragmented global coordination further intensify the problem, especially in resource-limited regions. effective resistance agents has contributed for spread of resistant and emergence Gram-negative bacteria in hospitals, slow adoption of innovative treatments, limited scientific understanding, ethical dilemmas in rapidly advancing technologies, and public hesitance toward restrictive policies. Consequently, AMR leads to prolonging illness, raising mortality, and escalating costs of healthcare; over, it restricts therapeutic options.[31,33]

VII. FUTURE PERSPECTIVES

The future battle against resistance (AMR) requires the unified One Health strategy which integrates animal, human and also the environmental health. Robust worldwide surveillance systems and the encouragement of international data exchange, along with fair access to novel therapies for low- and middle-income nations, are critical. Through close collaboration among healthcare providers, researchers, policymakers, and global organizations, AMR can be effectively curtailed, ensuring that antibiotics remain potent for future generations.[34]

VIII. RESULTS

Antimicrobial resistance is a growing concern impelled by genetic mutations, horizontal gene transfer, and overuse of antibiotics in human healthcare, livestock production, and of agriculture. The primary mechanisms is resistance include enzymatic degradation of drugs, modification of target sites on cellular components or ribosomes. Current strategies for combat AMR involve global surveillance, national policy initiatives, hospital-based stewardship programs, infection prevention, and public awareness campaigns. Emerging therapeutic innovations, and AI-driven precision medicine—offer promising alternatives to conventional antibiotics. Technological and diagnostic advancements, such as point-of-care molecular assays and AI-powered predictive systems, enhance rapid infection detection and treatment. Despite progress, challenges persist—slow antibiotic development, high drug costs, complex regulatory frameworks, and environmental dissemination of resistance highlight the urgent need for integrated One Health approaches supported by international cooperation and equitable access to novel interventions.

IX. DISCUSSION

Antimicrobial resistance is a global health threat that is considered to be driven by the increasing use of antibiotics, the rapid ability of microbes to adapt, and the slow development of new drugs. To address this, it can be approached from different perspectives: prudent application of antibiotics, infection prevention, and stewardship programs, coupled with various novel therapy as phage therapy, AMPs, nano-antibiotics, and the CRISPR-based interventions. Rapid diagnostics, AI-driven optimization of treatment, and genome-based tools will help select appropriate therapies and monitor resistance patterns more effectively. Combined therapeutic approaches involving probiotics, phytochemicals, and drug delivery systems (DDS) enhance treatment efficacy while minimizing the development of resistance.

X. CONCLUSION

Addressing antimicrobial resistance (AMR) requires a comprehensive and unified global response that considers all aspects of health. Strengthening international collaboration and enhancing surveillance systems are essential for tracking resistance patterns and implementing timely interventions. Key priorities to confront this growing challenge are the use of existing antimicrobials; control measures and tight infection prevention; and stewardship programs, complemented by novel therapies such as phage therapy, AMP's, nanomedicine, and the immunotherapy. Equally important are harmonized global policies, adoption and ensuring equitable access to new antimicrobial treatments. Rigorous scientific research, responsible clinical practices, and much closer international collaboration would mean that humanity can rise above AMR and also retain the effect of antimicrobials for future.

XI. CONFLICT OF INTEREST

The authors have no conflict of interest regarding this investigation.

XII. ACKNOWLEDGEMENT

The authors would like to thank Ms Sana Shaikh(Assistant Professor) from Indala Institute of Pharmacy for her kind support.

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