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Antimicrobial resistance: Impact and control strategies

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Abstract
Across the world, antimicrobial resistance (AMR) has emerged as a major public health threat. A growing number of infections caused by bacteria, parasites, viruses, and fungi are at high risk due to the threat posed by multidrug resistant strains. AMR outbreak is one of the most serious threats to world health, with long-term humanitarian and economic impacts if it is not addressed swiftly. The antibiotic resistance crisis has been attributed to the misuse and overuse of these drugs, as well as a lack of novel drug development by the pharmaceutical industry due to weakened economic incentives and difficult regulatory requirements. Here we discuss about the impact and challenges of AMR in the global public health sector and the novel approaches that has to be developed in order to fight against the these multi drug resistant microbes.

Keywords: Antimicrobial resistance (AMR), infection, public health

1. Introduction

Sir Alexander Fleming's discovery of penicillin in 1928 marked the beginning of the modern age of antibiotics. Since then, antibiotics have revolutionized the contemporary medicine and saved millions of lives [1]. The mid-twentieth century was the golden age for the development of effective drugs for antibacterial chemotherapy, when most of the currently used antimicrobial agents were discovered [2]. Antimicrobials have significantly increased our health and life expectancy but the phenomenon of antimicrobial resistance (AMR) that has emerged in response to antibiotics substantially decreased the effectiveness of these antibiotics [3]. AMR is one of the most important public health concerns today and poses a threat to human beings, animals and all other living creature wellness on a global scale. If AMR is not controlled, it could become a significant healthcare danger and trigger another pandemic. In accordance to the World Health Organization (WHO), if infections with resistant bacteria spread throughout the world, the number of infections-related fatalities will exceed 10 million per year by 2050, with a global economic burden of more than $100 billion [4, 5]. Pharmaceutical industry attempts to create new antibiotics, a technique that had previously been successful in battling resistant microbes, have practically come to a standstill because of financial and regulatory challenges [5, 6]. As a result, the long-term approach should focus on techniques to prevent the development of resistance, the spread of resistant organisms and to treat the infections caused by multi drug resistant bacteria [7].

2. Mechanism of resistance

The Mechanism of resistance in a more simplified representation, the antibiotic that inhibits susceptible organisms and the genetic resistance determinant in the bacteria that the antibiotic chooses as targets can be considered as the two primary variables in the equation that represents the resistance problem [8, 9]. Drug resistance genes can be transmitted from one bacterium to another by mechanisms like plasmids, transposons, bacteriophages or naked genetic material. The overuse of antibiotics is definitely a factor in the development of resistance [10, 11]. Long-term usage of a single antimicrobial drug selects for organisms that are resistant to not only that antibiotic, but several others as well. Epidemiological studies have shown a direct link between antibiotic use and the establishment and spread of resistant bacterium strains.

Pseudomonas aeruginosa, *Escherichia coli*, vancomycin-resistant enterococci (VRE), *Klebsiella pneumoniae* bearing extended-spectrum-lactamases (ESBL), methicillin-resistant *Staphylococcus aureus* (MRSA), *Acinetobacter baumannii* and vancomycin-resistant MRSA are some of the most challenging Multi drug resistant organisms [12, 13, 14], As shown in Figure 1.

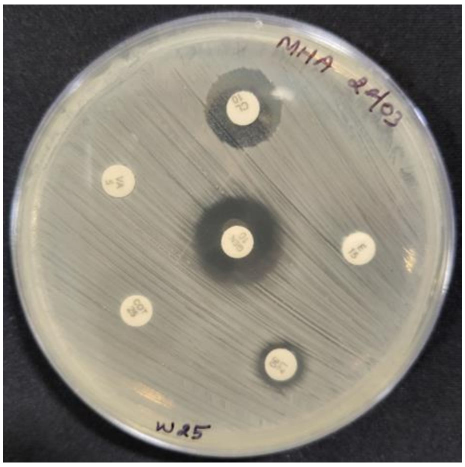

Fig 1: ABST result: Bacterial isolate (*Klebsiella species*) showing Multi-Drug Resistance (MDR).

3. Impact of AMR

3.1 Global impact of AMR

The WHO launched the Global Antimicrobial Resistance and Use Surveillance System (GLASS) in 2015 to gradually incorporate official national antimicrobial resistance data, such as use of antimicrobial medicines, monitoring of resistance and antimicrobial resistance in the environment and food chain, to reveal the burden of resistance to antimicrobial drugs, patterns of resistance, determinants, and the cost of infection (World Health Organization, 2017) [15, 16]. According to the most extensive evaluation of the global economic impact of AMR based on the statistical analysis of the data from 204 countries that were available in 2019, AMR is thought to be responsible for 1.27 million of the 4.95 million deaths related to AMR [15].

3.2 Impact of AMR on animal and human health

Antimicrobial resistance (AMR) has emerged as a complex and critical global challenge affecting both human and animal health. The widespread misuse and overuse of antibiotics across multiple sectors—including human healthcare, veterinary medicine, and agriculture—have significantly accelerated the development and spread of drug-resistant microbial strains. Prolonged and excessive use of antibiotics has been a major contributing factor in the emergence and evolution of antibiotic-resistant microorganisms [14, 15]. Moreover, the slow pace of developing new antimicrobial agents further intensifies the problem, as the emergence of resistance is outstripping the discovery of effective therapeutic alternatives [16, 17]. AMR has become one of the most critical public health threats of the 21st century. Infections that were once readily treatable are now increasingly difficult to manage, leading to significant clinical challenges [16]. The diminishing efficacy of first-line antimicrobial agents has necessitated greater dependence on second-and third-line therapies, which are typically more costly, associated with higher toxicity, and require prolonged treatment durations. In the absence of effective antibiotics, routine medical interventions such as surgery, organ transplantation, chemotherapy, and neonatal care may become significantly more hazardous due to the diminished ability to control infections. Among the most critical multidrug-resistant (MDR) threats in clinical settings are the 'ESKAPE' pathogens—*Enterococcus faecium*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, and *Enterobacter* species—which are known for their high resistance and capacity to evade antimicrobial treatment. The widespread impact of AMR extends beyond public health, significantly affecting agriculture, economic stability, national security, and international trade. These interconnected consequences underscore the urgent need for a comprehensive One Health approach that integrates human, animal, and environmental health surveillance and interventions. Such a coordinated strategy is essential to mitigate both the current and potential future effects of AMR on animal health, which, in turn, increases the risk of transmission to humans [14, 16, 17].

4. Strategies to combat AMR

The main Strategies to combat AMR includes the need for novel solutions to the antibiotic resistance challenge is critically important because investing on antibiotics in the pharmaceutical industry is challenging. Researchers involved in associated fields are exploring antimicrobials and bacteriophages using novel methods, creating novel medications, and creating new antibacterial technology and treatments [18]. The modern innovative technique that can be developed to combat resistance include combination drugs therapy, faecal microbiota transplantation, nanoparticles, and photodynamic light therapy, bacteriophage therapy, antimicrobial peptides and antimicrobial adjuvants to prevent antibiotic resistance and other therapeutic strategies. Among these antimicrobial peptides are broad-spectrum, ultra-fast-acting agents that mimic the body's innate immune system to kill microorganisms that can be the possible alternative for antibiotics [5, 17]. Along with these the overuse of antibiotics in agriculture and livestock field can be reduced by establishing and enforcing guidelines for the use of antibiotics in food animals, especially farmed seafood and ensuring the use of environmentally friendly manure and fertilizers to improve agricultural practices [18, 19].

5. Antimicrobial Resistance: Future Burden and Emerging Challenges

There is a critical lack of global coordination, as fragmented and localized containment efforts fail to keep pace with the rapid evolution of pathogenic bacteria driven by widespread antimicrobial use in human healthcare, agriculture, and environmental settings [10. 19]. In addition to causing direct mortality and significant economic losses, the declining efficacy of antimicrobial agents poses a serious threat to modern medicine [18, 20]. This decline may facilitate the re-emergence of bacterial infections that were once effectively controlled by antibiotics. Particularly at risk are cancer patients, immunocompromised individuals, and those undergoing surgical procedures, who are increasingly vulnerable to infections caused by extensively or pan-drug-resistant bacterial strains. Furthermore, the cumulative burden of prevalent infectious diseases such as pneumonia, tuberculosis, and gastrointestinal infections is likely to escalate significantly in a post-antibiotic era [17, 18, 19]. The accelerating loss of effective antimicrobial agents threatens to reverse decades of medical advancement, potentially returning humanity to an era where bacterial infections posed major environmental and public health challenges [20, 21].

The effective control of AMR requires a coordinated, One Health approach that integrates human, animal, and environmental health strategies [22]. Key interventions include the prudent use of antimicrobials, robust surveillance systems, public awareness, research into novel therapies, and strong policy frameworks to regulate antimicrobial usage. Strengthening infection prevention and control, enhancing diagnostic capabilities, and promoting global collaboration are essential to mitigating the spread of resistance [23, 24].

6. Conclusions

In light of the accelerating emergence of antimicrobial resistance and the declining pace of new antibiotic discovery exacerbated by limited financial investment the threat of a post-antibiotic era is becoming a stark reality. Antimicrobial resistance poses a profound threat to global health, agriculture, and economic stability. The widespread and often indiscriminate use of antimicrobials in human medicine, veterinary care, and food production has accelerated the emergence of resistant pathogens, undermining decades of progress in infectious disease control. The consequences include increased morbidity, mortality, treatment costs, and the risk of untreatable infections. Without immediate and coordinated global action, even routine infections and minor injuries could once again become life-threatening. Addressing this crisis requires urgent development and validation of innovative therapeutic approaches that target host-microbial interactions and pathogen-specific molecular mechanisms. Additionally, strengthening regulatory oversight and enforcing stringent guidelines on antibiotic usage are crucial to preserving the efficacy of existing treatments and safeguarding public health for future generations.

Combating AMR is not solely a scientific or medical challenge, but a societal responsibility. Sustained commitment and collective action across all sectors and nations are imperative to preserve the effectiveness of existing antimicrobials and safeguard public health for future generations.

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8. Conflict of Interest

Authors declare there is no conflict of interest.

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