

A Review on Pre- and Post-COVID-19 Evaluation of Antimicrobial Susceptibility for Healthcare-associated Infections

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ABSTRACT:

Healthcare-associated infections (HAIs) pose a significant threat to patient safety, with antimicrobial resistance (AMR) exacerbating the challenge. The COVID-19 pandemic introduced profound shifts in infection control practices, antimicrobial usage, and diagnostic strategies, impacting antimicrobial susceptibility patterns in HAIs. This review examines the pre- and post-COVID-19 trends in antimicrobial susceptibility for common HAIs, exploring the influences of pandemic-era healthcare protocols. Pre-pandemic data highlighted rising resistance levels due to antibiotic misuse, particularly in intensive care units (ICUs). The pandemic accelerated the overuse of broad-spectrum antibiotics, driven by misdiagnosed bacterial superinfections and limited diagnostic resources. Consequently, post-pandemic surveillance data indicate an alarming increase in resistant pathogens, including *Klebsiellapneumoniae*, *Acinetobacterbaumannii*, and *Candidaauris*. This review also addresses the role of strengthened infection control policies during COVID-19, such as enhanced hygiene measures and antimicrobial stewardship programs, which varied in their effectiveness across settings. Furthermore, it highlights the need for comprehensive, real-time AMR monitoring systems and global collaboration to mitigate future resistance challenges. By integrating lessons learned from the pandemic, this review emphasizes the importance of balancing antimicrobial stewardship with effective infection control strategies to safeguard public health against evolving resistance trends in HAIs.

1.Introduction

Healthcare-associated infections (HAIs) are infections that patients acquire during medical care, which can complicate treatment outcomes and significantly burden public health systems. They contribute to increased rates of illness, mortality, and healthcare expenditures globally. These infections can be caused by bacteria, viruses, fungi, or parasites, with bacterial pathogens being the predominant agents. Antimicrobials, including antibiotics, antivirals, antifungals, and antiparasitics, are critical tools for preventing and treating such infections. However, antimicrobial resistance (AMR) arises when microorganisms develop mechanisms to evade the effects of these drugs, rendering them ineffective. AMR naturally evolves through genetic mutations but is exacerbated by factors such as the excessive and inappropriate use of antimicrobials in humans, animals, and agriculture. This growing resistance complicates the management of HAIs, resulting in prolonged hospital stays, increased treatment costs, and higher mortality rates. Addressing AMR requires coordinated global efforts in antimicrobial stewardship, infection control, and the development of new treatment strategies.

1.InternationalApprehension

Antimicrobial medicines are fundamental to modern healthcare, enabling the treatment of infections and the safe execution of critical medical procedures, such as cancer treatments,

caesarean sections, organ transplants, and orthopedic surgeries. However, the rise of antimicrobial resistance (AMR) poses a severe threat to these advancements. Drug-resistant infections not only compromise human health but also impact animals, agriculture, and food security by reducing farm productivity. The economic and healthcare costs of AMR are profound, as it necessitates the use of more expensive treatments, prolonged hospital stays, and increased intensive care, while diminishing patient productivity and straining caregivers.

AMR is a global issue that transcends national borders, affecting countries across all income levels. Contributing factors include inadequate access to clean water, sanitation, and hygiene (WASH); insufficient infection prevention and control measures in healthcare and agricultural settings; limited access to quality medicines, diagnostics, and vaccines; low public awareness; and weak enforcement of relevant policies. Vulnerable populations, particularly those in low-resource settings, bear the brunt of AMR, experiencing its drivers and consequences disproportionately. Coordinated global action is essential to mitigate AMR's multifaceted impacts.



Fig. 1. Available on resistance for nine selected bacteria/antibacterial drug combinations (2013). Source: WHO.

1. What is the present situation?
a. Drug-resistance in bacteria

The growing prevalence of antibiotic resistance presents a serious global health threat, reducing the effectiveness of widely used antibiotics against common bacterial infections. The 2022 Global Antimicrobial Resistance and Use Surveillance System (GLASS) report revealed troubling resistance levels in key pathogens. For instance, 42% of *Escherichia coli* strains were resistant to third-generation cephalosporins, and 35% of *Staphylococcus aureus* cases showed resistance to methicillin. Among *E. coli* infections causing urinary tract issues, approximately 20% demonstrated reduced susceptibility to first-line antibiotics such as ampicillin, co-trimoxazole, and fluoroquinolones, complicating treatment.

Klebsiellapneumoniae, a gut bacterium often linked to severe infections, exhibited heightened resistance against critical antibiotics. Consequently, reliance on last-resort treatments like

carbapenems is rising, but resistance to these drugs is also increasing globally. The Organization for Economic Cooperation and Development (OECD) forecasts that resistance to last-line antibiotics may double by 2035 compared to 2005 levels. These findings emphasize the urgent need for enhanced antimicrobial stewardship, broader surveillance networks, and global collaboration to combat antimicrobial resistance effectively. For purposes, reliable references include the GLASS 2022 report, WHO antimicrobial resistance updates, and OECD projections on AMR trends.

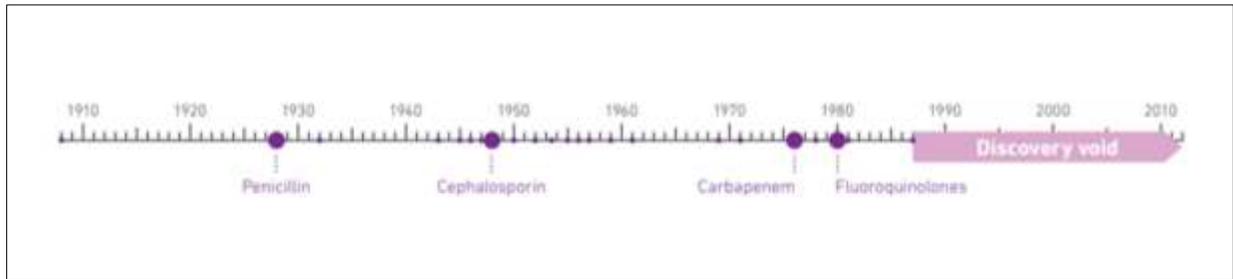


Fig. 2. Over the last 30 years, no major new types of antibiotics have been developed. Source: WHO.

b. Drug resistance in fungi

The rise in drug-resistant fungal infections has prompted the World Health Organization (WHO) to closely monitor their prevalence and impact on public health. Fungal infections are often challenging to treat, particularly due to complications like drug-drug interactions in patients managing other conditions, such as HIV. One major concern is the emergence and global spread of *Candida auris*, a multidrug-resistant fungal pathogen that causes invasive infections. In response, the WHO has developed a Fungal Priority Pathogens List (FPPL), which was informed by an extensive global analysis of fungal infections and antifungal resistance. This initiative aims to guide research priorities and public health strategies for addressing the growing threat of drug-resistant fungi.

c. Drug resistance in HIV, tuberculosis and malaria

HIV drug resistance (HIVDR) arises from mutations in the HIV genome that impair the effectiveness of antiretroviral (ARV) drugs in suppressing viral replication. This resistance can either be transmitted during initial infection or develop due to factors such as poor adherence to therapy or drug-drug interactions. HIVDR exacerbates the HIV epidemic by increasing infection rates, morbidity, and mortality. To combat this, the World Health Organization (WHO) advocates for regular HIVDR surveillance to guide the selection of effective ARV regimens for prevention and treatment. Tuberculosis (TB) is another significant driver of antimicrobial resistance. Multidrug-resistant TB (MDR-TB) results from strains resistant to isoniazid and rifampicin, the two most potent first-line TB drugs. While MDR-TB can be treated using second-line drugs, these treatments are often expensive, toxic, and less effective. In severe cases, further resistance to second-line drugs emerges, leaving patients with very few therapeutic options. MDR-TB is thus a major global health crisis, posing a significant threat to health security. Alarmingly, in 2022, only about 40% of individuals with drug-resistant TB were able to access treatment.

The rise of drug-resistant parasites presents a significant challenge to malaria control efforts. Artemisinin-based combination therapies (ACTs), the primary treatment for uncomplicated *Plasmodium falciparum* malaria in endemic regions, face increasing threats from partial resistance to artemisinin and its partner drugs. This resistance complicates treatment

selection and necessitates vigilant monitoring. Since 2001, partial resistance to artemisinin or its partner drugs has been identified in the Greater Mekong Subregion, affecting multiple countries. In the WHO Eastern Mediterranean Region, resistance to the partner drug sulfadoxine-pyrimethamine has resulted in treatment failures, necessitating a shift to alternative ACTs. Furthermore, in Africa, mutations associated with partial resistance to artemisinin have been detected in several countries. While the tested ACTs remain effective, the potential for resistance to spread further poses a critical public health risk. Strengthened surveillance systems are essential to track and mitigate this growing threat..

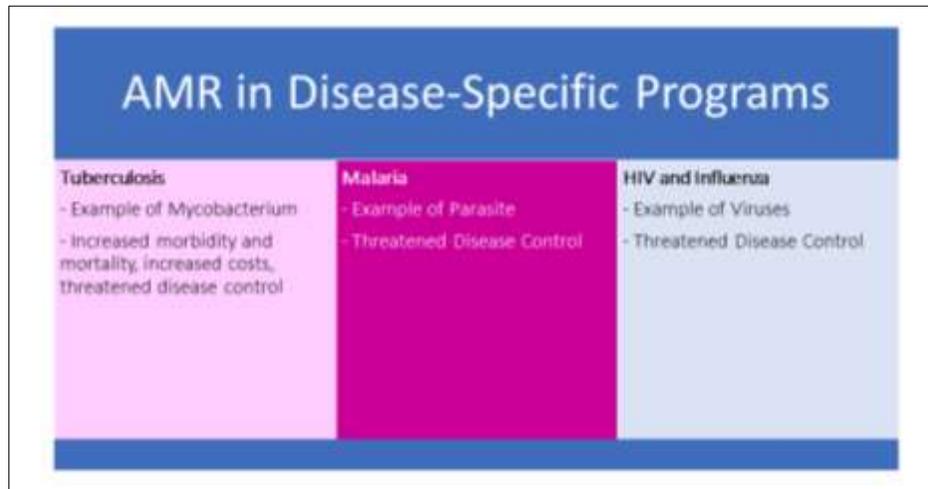


Fig. 3. AMR in Disease-Specific Programs (Tuberculosis, Malaria, HIV and Influenza).
 Source: WHO.

d. Drug resistance in neglected tropical diseases (NTDs)

The rise of drug resistance to treatments for neglected tropical diseases (NTDs) poses a critical challenge to global efforts aimed at controlling, eliminating, and eradicating these diseases. NTDs disproportionately impact vulnerable and marginalized populations. Resistance has been documented in several key treatments, such as dapsons, rifampin, and clofazimine for leprosy in multiple countries. Anti-helminthic resistance, primarily observed in veterinary applications, raises concerns since many of these drugs are also used in human medicine. Additionally, resistance to medications like melarsoprol for human African trypanosomiasis and pentavalent antimonials and miltefosine for leishmaniasis has been reported. To combat these challenges, it is vital to monitor drug efficacy, implement strategies to delay resistance, and bolster the development of alternative or second-line therapies. For instance, the World Health Organization (WHO) provides guidance on resistance surveillance within global leprosy elimination programs. WHO also supports the controlled distribution, standardized use, safety evaluation, and efficacy monitoring of medicines, including donated treatments, within NTD programs. Strengthening these frameworks is essential to mitigate resistance and ensure sustainable NTD management.

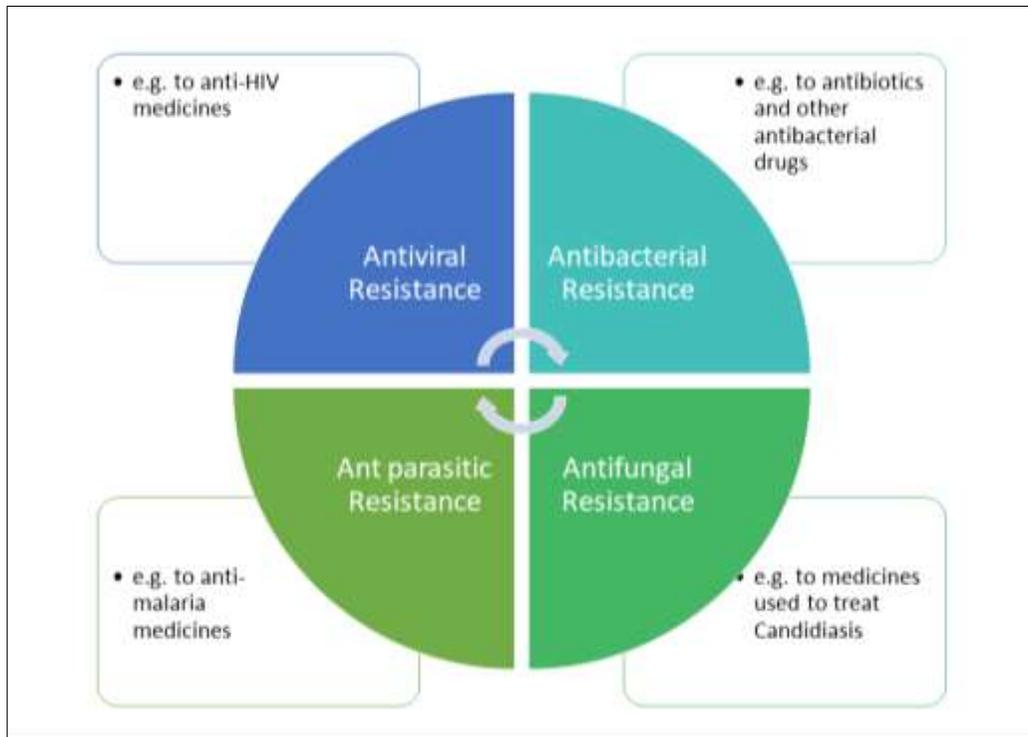


Fig. 4. AMR is a natural phenomenon accelerated by use of antimicrobial medicines. Resistant strains survive and aggregate. Source: WHO.

2. Impact of COVID-19 on Healthcare and HAIs

The COVID-19 pandemic, triggered by SARS-CoV-2, has profoundly disrupted healthcare systems globally. Beyond overwhelming healthcare facilities, it has significantly impacted the dynamics of healthcare-associated infections (HAIs) and antimicrobial resistance (AMR). Factors such as the widespread use of antibiotics, modifications in infection prevention practices, and the immense strain on healthcare resources during the pandemic have likely influenced the prevalence and susceptibility patterns of HAIs. These shifts underscore the need for enhanced surveillance and adaptive strategies to address the evolving challenges posed by AMR and HAIs in the post-pandemic era.

a. Importance of Studying Antimicrobial Susceptibility

Analyzing antimicrobial susceptibility involves evaluating the effectiveness of various antimicrobial agents against specific pathogens. This process is essential for selecting appropriate treatments, curbing the spread of resistant microorganisms, and shaping public health strategies. Assessing variations in antimicrobial susceptibility before and after the COVID-19 pandemic offers valuable insights into how the pandemic has influenced antimicrobial resistance (AMR). Such data can guide the development of targeted interventions for better management of healthcare-associated infections (HAIs) and contribute to formulating robust strategies to combat AMR in the future.

b. Healthcare-associated Infections

Healthcare-associated infections (HAIs) refer to infections that patients acquire while receiving medical care in hospitals or other healthcare settings. These infections are a significant challenge in healthcare delivery, affecting millions of individuals globally each year. Common HAIs include central line-associated bloodstream infections (CLABSIs), catheter-associated urinary tract infections (CAUTIs), surgical site infections (SSIs), and ventilator-associated

pneumonia (VAP). These conditions can lead to increased patient morbidity, extended hospital stays, and higher healthcare costs, highlighting the critical need for effective prevention and management strategies.

c. Antimicrobial Resistance: A Growing Threat

Antimicrobial resistance is one of the most pressing health issues of our time. The World Health Organization (WHO) has declared AMR a global health emergency. Bacteria such as Methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant Enterococci (VRE), and multidrug-resistant Gram-negative bacteria are significant contributors to AMR in healthcare settings. The misuse and overuse of antibiotics in humans, animals, and agriculture are key drivers of AMR. In healthcare settings, inadequate infection prevention and control practices further exacerbate the problem.

The COVID-19 pandemic has influenced antimicrobial resistance in several ways. During the early stages of the pandemic, there was widespread use of antibiotics to treat COVID-19 patients, despite the viral nature of the disease. This increased antibiotic usage raised concerns about the acceleration of AMR. Changes in healthcare practices during the pandemic, such as the increased use of personal protective equipment (PPE) and modifications in infection control protocols, have also impacted the incidence and management of HAIs. Furthermore, the diversion of healthcare resources to manage COVID-19 patients has affected routine infection control measures and antibiotic stewardship programs. Before the COVID-19 pandemic, the prevalence of AMR in HAIs was already a significant concern. Studies have documented high rates of resistance to commonly used antibiotics among HAI pathogens. For instance, MRSA and VRE were prevalent in many healthcare settings, posing challenges to effective infection management. Gram-negative bacteria, such as *Escherichia coli* and *Klebsiella pneumoniae*, have shown increasing resistance to antibiotics like carbapenems and cephalosporins.

These trends underscore the need for ongoing surveillance and effective antimicrobial stewardship to mitigate the impact of AMR on patient outcomes. During the COVID-19 pandemic, several studies reported changes in the antimicrobial susceptibility patterns of HAI pathogens. The increased use of broad-spectrum antibiotics, often without appropriate indications, contributed to these changes. Some studies noted a rise in infections caused by multidrug-resistant organisms (MDROs) during the pandemic. The pandemic also disrupted routine infection control practices, potentially leading to increased transmission of resistant pathogens within healthcare settings. Additionally, the focus on COVID-19 patients sometimes resulted in delayed diagnosis and treatment of other infections, including HAIs, affecting patient outcomes. Several factors have contributed to the changes in antimicrobial susceptibility patterns observed during the COVID-19 pandemic:

1. **Increased Antibiotic Use**
2. **Altered Infection Control Practices**
3. **Resource Allocation**
4. **Delayed Diagnosis and Treatment**

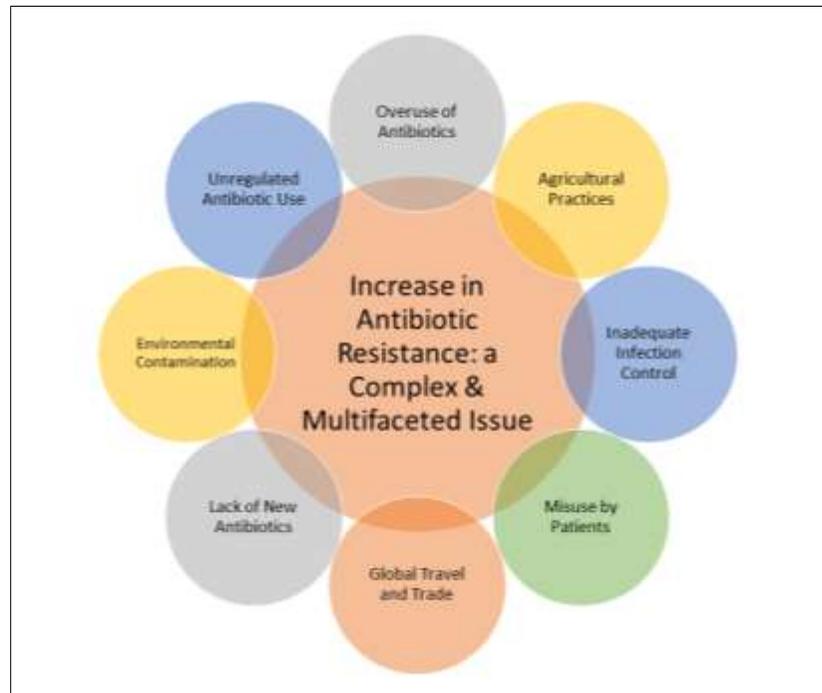


Fig. 6. Increase in antibiotic resistance is a complex and multifaceted issue driven by several factors.

Antimicrobial stewardship programs (ASPs) are critical for optimizing the use of antibiotics and combating AMR. ASPs aim to ensure that patients receive the right antibiotic, at the right dose, for the right duration, thereby minimizing the emergence of resistance. Effective ASPs involve multidisciplinary teams, including physicians, pharmacists, and infection control practitioners, working together to improve antibiotic prescribing practices. Based on the findings from this study, several recommendations can be made to enhance antimicrobial stewardship and infection control practices in the context of HAIs:

1. **Strengthen ASPs.**
2. **Enhance Infection Control Measures**
3. **Surveillance of AMR.**
4. **Education and Training.**
5. **Policy and Regulation.**

The study of antimicrobial susceptibility for healthcare-associated infections before and after the COVID-19 pandemic is vital for understanding the impact of the pandemic on AMR and informing future strategies for managing HAIs. The findings highlight the need for strengthened antimicrobial stewardship, enhanced infection control practices, and continuous surveillance to combat the growing threat of AMR. By implementing these recommendations, healthcare systems can improve patient outcomes, reduce healthcare costs, and safeguard public health. Antimicrobial resistance (AMR) is a significant global public health threat that predates the COVID-19 pandemic but has been exacerbated by it. The World Health Organization (WHO) and various health agencies worldwide have highlighted the urgency of addressing AMR due to its potential to undermine the effectiveness of antibiotics and other antimicrobial agents, making common infections harder to treat and increasing the risk of disease spread, severe illness, and death. The COVID-19 pandemic, caused by the SARS-CoV-2 virus, has had multifaceted impacts on healthcare systems, including the patterns of antimicrobial usage and resistance. This review of literature aims to elucidate the impact of COVID-19 on AMR by examining changes in antibiotic use, infection control practices, and the broader implications for public health.

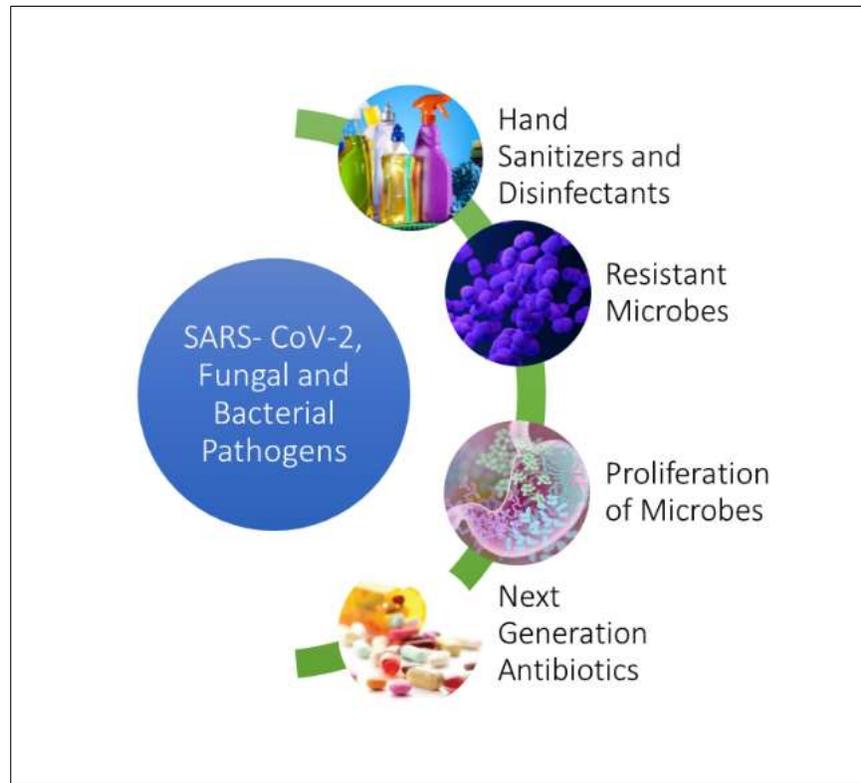


Fig. 7. Misuse of Disinfectants leads to the Proliferation of Resistant Microbes Requiring Next-generation Antibiotics.

5. Pre-COVID-19 Antimicrobial Susceptibility Patterns

Antimicrobial resistance (AMR) poses one of the most significant threats to global public health, rendering common infections increasingly difficult to treat. Prior to the COVID-19 pandemic, extensive research and surveillance had documented the patterns and trends of antimicrobial susceptibility and resistance across various pathogens. This review delves into the antimicrobial susceptibility patterns before the COVID-19 era, exploring key pathogens, the geographic variability of resistance, and the implications for treatment and public health policies. AMR occurs when microorganisms such as bacteria, viruses, fungi, and parasites evolve to resist the effects of antimicrobial drugs. This resistance undermines the efficacy of treatments, leading to prolonged illnesses, higher medical costs, and increased mortality. Several factors contribute to AMR, including the overuse and misuse of antibiotics in human medicine and agriculture, lack of new antibiotic development, and insufficient infection control practices.

a. Global Patterns of Antimicrobial Susceptibility: *Bacterial Pathogens*

Staphylococcus aureus

Staphylococcus aureus, particularly methicillin-resistant *Staphylococcus aureus* (MRSA), has been a major concern in both healthcare and community settings. Pre-COVID-19 data indicated a significant prevalence of MRSA, with varying rates across regions. For example, Europe reported decreasing MRSA rates in some countries due to effective infection control measures, while the United States and parts of Asia continued to see high MRSA prevalence.

Enterobacteriaceae

Enterobacteriaceae, a family of bacteria including *Escherichia coli* and *Klebsiella pneumoniae*, showed increasing resistance to carbapenems, a class of last-resort antibiotics. Carbapenem-resistant *Enterobacteriaceae* (CRE) were particularly problematic in healthcare settings, with notable outbreaks reported worldwide. The global spread of CRE was attributed to various factors,

including international travel, medical tourism, and the spread of mobile genetic elements carrying resistance genes.

Mycobacterium tuberculosis

Drug-resistant tuberculosis (TB) has been a significant public health issue, with multidrug-resistant TB (MDR-TB) and extensively drug-resistant TB (XDR-TB) complicating treatment efforts. Surveillance data from the World Health Organization (WHO) indicated that MDR-TB accounted for approximately 3.4% of new TB cases and 18% of previously treated cases globally. The emergence of XDR-TB, resistant to at least four of the core anti-TB drugs, posed severe treatment challenges.

Table 1. Selected Bacteria/Resistance Combinations. Source: WHO.

Bacterium	Resistance/Decreased Susceptibility to:
<i>Escherichia coli</i>	3 rd Generation Cephalosporins, Fluoroquinolones
<i>Klebsiella pneumoniae</i>	3 rd Generation Cephalosporins, Carbapenems
<i>Staphylococcus aureus</i>	Methicillin (beta-lactam antibiotics) i.e. MRSA
<i>Streptococcus pneumoniae</i>	Penicillin
Nontyphoidal Salmonella (NTS)	Fluoroquinolones
<i>Shigella</i> Species	Fluoroquinolones
<i>Neisseria gonorrhoeae</i>	3 rd Generation Cephalosporins

b. Geographic Variability in Antimicrobial Resistance

The prevalence of AMR varied significantly across different regions and countries, influenced by factors such as antibiotic usage patterns, healthcare infrastructure, and regulatory policies. Europe exhibited diverse AMR patterns, with Northern European countries generally reporting lower resistance rates compared to Southern and Eastern Europe. This disparity was linked to stricter antibiotic stewardship programs and better infection control practices in the north. The European Antimicrobial Resistance Surveillance Network (EARS-Net) provided valuable data on resistance trends, highlighting areas for improvement and successful interventions. Asia faced a significant burden of AMR, with high rates of resistance reported for various bacterial pathogens. Countries like India and China were notable for the widespread availability and use of over-the-counter antibiotics, contributing to the high prevalence of resistant strains. In Southeast Asia, the spread of resistance was exacerbated by weak regulatory frameworks and limited access to quality healthcare. African countries faced unique challenges in combating AMR due to limited resources, inadequate laboratory infrastructure, and the high burden of infectious diseases. Surveillance data were often sparse, but available studies indicated high levels of resistance to commonly used antibiotics. Efforts to address AMR in Africa included strengthening laboratory capacities, improving antibiotic stewardship, and enhancing public awareness.

c. Key Drivers of Antimicrobial Resistance

Several factors were identified as key drivers of AMR prior to the COVID-19 pandemic:

- 1. Inappropriate Antibiotic Use:** Overprescription, self-medication, and the use of antibiotics for non-bacterial infections were major contributors to the development of resistance.
- 2. Agricultural Practices:** The use of antibiotics in livestock for growth promotion and disease prevention contributed significantly to the spread of resistance genes from animals to humans.

3. **Inadequate Infection Control:** Poor infection prevention and control measures in healthcare settings facilitated the transmission of resistant pathogens.
4. **Global Travel and Trade:** The movement of people and goods across borders enabled the rapid spread of resistant strains globally.
5. **Lack of New Antibiotics:** The pharmaceutical pipeline for new antibiotics was drying up, with fewer new drugs being developed to replace those rendered ineffective by resistance.

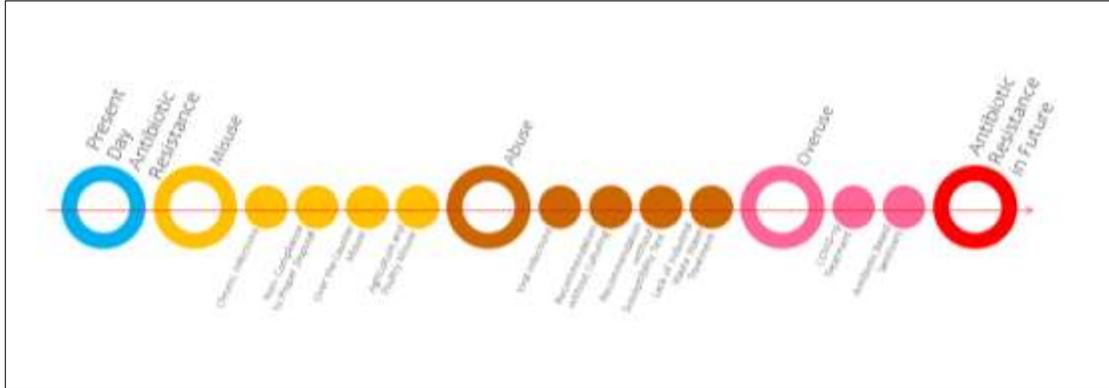


Fig 5. External Factors Responsible for Increase in Antibiotic Resistance. Modified from Lobie et al. 2021

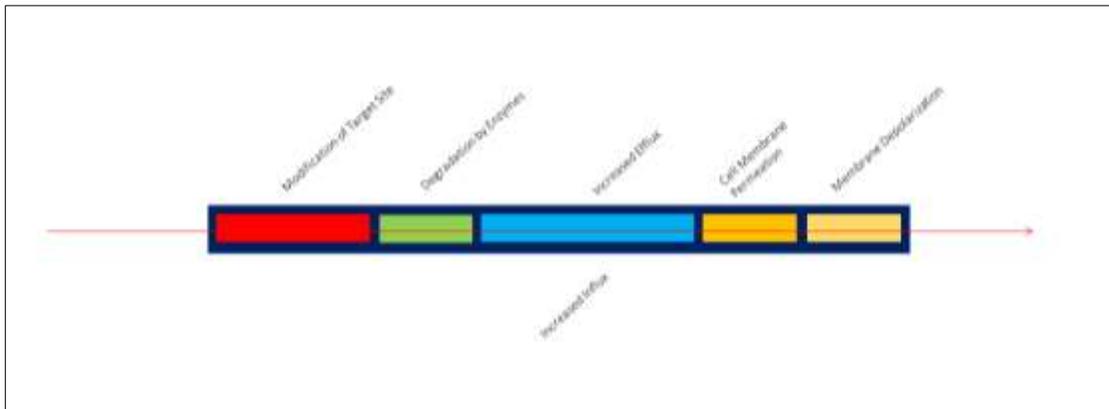


Fig 6. Internal Factors Responsible for Increase in Antibiotic Resistance.

d. Surveillance and Reporting of Antimicrobial Susceptibility

Surveillance networks played a crucial role in monitoring AMR trends and guiding public health interventions. The European Antimicrobial Resistance Surveillance Network provided comprehensive data on AMR trends in Europe, facilitating comparisons across countries and informing policy decisions (EARS-Net). The Global Antimicrobial Resistance Surveillance System, established by WHO, aimed to harmonize AMR surveillance worldwide, providing a platform for countries to share data and track resistance patterns (GLASS). The National Antimicrobial Resistance Monitoring System in the United States focused on resistance in foodborne pathogens, bridging the gap between human and animal health (NARMS).

A widely used method where antibiotic-impregnated disks are placed on an agar plate inoculated with the bacteria of interest. Zones of inhibition around the disks are measured to determine susceptibility (Disk Diffusion Test). A quantitative method that determines the minimum inhibitory concentration (MIC) of antibiotics by diluting them in broth and observing bacterial growth (Broth Micro-dilution). Instruments like VITEK and Phoenix provided rapid and accurate AST results, facilitating timely clinical decisions (Automated Systems).

e. Implications for Treatment and Public Health

The rising prevalence of AMR had profound implications for the treatment of infectious diseases and public health policies. The effectiveness of standard treatment regimens was compromised, leading to longer hospital stays, higher medical costs, and increased mortality. In response, public health agencies emphasized the importance of antimicrobial stewardship, infection control, and the development of new antibiotics. Pre-COVID-19 antimicrobial susceptibility patterns underscored the critical need for concerted efforts to combat AMR. The global variability in resistance trends highlighted the importance of tailored interventions and international collaboration. As the world continues to grapple with the implications of AMR, lessons learned from pre-pandemic patterns can inform strategies to mitigate the threat and safeguard the efficacy of antimicrobial treatments.

6. Impact of COVID-19 on Antimicrobial Resistance

a. Pre-Pandemic Context of Antimicrobial Resistance

Before the onset of the COVID-19 pandemic, AMR was already a critical issue, with estimates suggesting that it could cause up to 10 million deaths annually by 2050 if unaddressed. Key drivers of AMR include the overuse and misuse of antibiotics in human medicine and agriculture, lack of new antibiotics development, and poor infection prevention and control measures. Common multidrug-resistant organisms (MDROs) such as Methicillin-resistant *Staphylococcus aureus* (MRSA), Carbapenem-resistant *Enterobacteriaceae* (CRE), and drug-resistant *Mycobacterium tuberculosis* were among the major concerns for healthcare settings worldwide. Surveillance data indicated rising trends in resistance across various pathogens, emphasizing the need for robust antimicrobial stewardship programs (ASPs).

b. Impact of COVID-19 on Antibiotic Use

During the COVID-19 pandemic, there was a notable increase in the use of antibiotics, even though COVID-19 is a viral infection for which antibiotics are ineffective. Studies have shown that a significant proportion of COVID-19 patients received antibiotics, often as a precautionary measure against potential bacterial co-infections. For instance, a study by Langford et al. (2021) found that up to 72% of COVID-19 patients were prescribed antibiotics despite bacterial co-infections being relatively rare. Early in the pandemic, the differentiation between COVID-19 and bacterial pneumonia was challenging due to overlapping clinical features, leading to empirical antibiotic use (Uncertainty in Diagnosis). Critically ill COVID-19 patients in intensive care units (ICUs) were at higher risk of secondary bacterial infections, prompting prophylactic and therapeutic antibiotic use (Secondary Infections). Initial treatment guidelines often recommended antibiotics for COVID-19 patients with suspected bacterial co-infections, contributing to higher prescription rates (Guideline Ambiguities).

c. Changes in Infection Control Practices

The pandemic also led to significant changes in infection control practices, which had both positive and negative impacts on AMR. Enhanced infection control measures such as increased use of personal protective equipment (PPE), rigorous hand hygiene, and environmental cleaning were implemented to curb the spread of SARS-CoV-2. While these measures helped reduce the transmission of COVID-19, they also had a beneficial impact on reducing other healthcare-associated infections (HAIs). However, the overwhelming focus on COVID-19 management sometimes resulted in the neglect of routine infection control practices for other pathogens, potentially facilitating the spread of MDROs. Reports indicated that the strain on healthcare systems, coupled with the reallocation of resources, led to lapses in infection control, such as reduced surveillance for HAIs and lapses in antimicrobial stewardship efforts.

d. Surveillance and Reporting Challenges

The pandemic disrupted traditional surveillance systems for AMR and HAIs. Many health facilities prioritized COVID-19 testing and treatment, which diverted attention and resources from routine AMR surveillance. This disruption has likely led to underreporting of AMR data during the pandemic period, complicating the assessment of the true impact of COVID-19 on AMR.

e. Specific Impacts on Multidrug-Resistant Organisms

Several studies have documented specific changes in the prevalence and resistance patterns of MDROs during the pandemic. For example, some hospitals reported an increase in MRSA infections during the pandemic, possibly due to the increased use of invasive devices and antibiotics in COVID-19 patients (Increased MRSA Cases). An increase in CRE infections was observed in some ICUs, correlating with higher antibiotic use and prolonged hospital stays for COVID-19 patients (Carbapenem-Resistant Enterobacteriaceae). The pandemic also saw a rise in opportunistic fungal infections, such as *Candida auris* and *Aspergillus*, particularly in immunocompromised COVID-19 patients. These pathogens are often resistant to multiple antifungal agents, complicating treatment (Fungal Infections).

f. Antimicrobial Stewardship During the Pandemic

Effective antimicrobial stewardship is essential for combating AMR, yet the pandemic posed significant challenges to ASPs. Many ASP activities were deprioritized as healthcare systems focused on managing COVID-19 cases. This included reduced auditing of antibiotic prescriptions, fewer stewardship rounds, and limited implementation of stewardship interventions. Despite these challenges, some hospitals adapted by integrating stewardship activities into COVID-19 care protocols. For instance, implementing rapid diagnostic testing for bacterial infections in COVID-19 patients helped reduce unnecessary antibiotic use. Telemedicine also emerged as a valuable tool for maintaining stewardship efforts remotely.

g. Long-Term Implications for AMR

The long-term implications of the COVID-19 pandemic on AMR are still unfolding. Several potential scenarios could emerge like increased AMR which is widespread and often indiscriminate use of antibiotics during the pandemic could accelerate the development of resistance, leading to higher AMR rates in the future. The pandemic has underscored the importance of robust infection control and stewardship programs, potentially leading to renewed focus and investment in these areas post-pandemic. The integration of advanced diagnostic technologies and digital health tools during the pandemic could improve AMR surveillance and reporting systems, facilitating better management of resistance patterns.

h. Policy and Research Recommendations

To address the impact of COVID-19 on AMR, several policy and research recommendations can be made like strengthening ASPs that reinforce the role of antimicrobial stewardship programs in healthcare settings, ensuring they are integrated into COVID-19 care protocols and beyond. Develop robust AMR surveillance systems that can adapt to crises and ensure continuous monitoring of resistance patterns (Enhancing Surveillance Systems). Support research on the development of new antibiotics, rapid diagnostic tools, and alternative therapies to combat resistant pathogens (Investing in Research). Educate healthcare providers and the public on the risks of antibiotic misuse and the importance of adherence to stewardship principles (Public Health Campaigns). Foster international collaboration to share data, best practices, and resources for combating AMR, recognizing it as a global health threat (Global Collaboration).

The COVID-19 pandemic has had a profound impact on antimicrobial resistance, highlighting both the vulnerabilities and strengths of current healthcare systems. While the increased use of antibiotics during the pandemic raises concerns about accelerating resistance, it also provides an opportunity to reinforce the importance of antimicrobial stewardship and infection control

measures. By learning from the challenges and successes of the pandemic response, healthcare systems can better prepare for future public health threats and mitigate the impact of AMR on global health.

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