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Lessons from COVID-19: Strengthening Antimicrobial Stewardship Prior and During Pandemics

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ABSTRACT

The COVID-19 pandemic has had a complex impact on the silent pandemic of antimicrobial resistance (AMR). While increased antibiotic misuse and disrupted antimicrobial stewardship (AMS) programs exacerbated AMR in some settings, heightened awareness and improved infection prevention measures implemented to control COVID-19 provided valuable lessons on sustaining these practices in the fight against AMR. This brief highlights lessons learned from the pandemic, such as the importance of access to antimicrobials and the urgent need for resilient and sustainable AMS integrated into pandemic preparedness, strengthening infection prevention and surveillance systems, enhancing access and use of diagnostics, and promoting a One Health approach. By leveraging these lessons, policymakers can build more resilient health systems, maintain the effectiveness of antimicrobials and be better prepared for future pandemics, particularly in developing countries. Immediate action is essential to protect public health and combat AMR effectively.

KEYWORDS: Antimicrobial Resistance (AMR); Antimicrobial Stewardship (AMS); COVID-19; Pandemic preparedness; One health approach; Sustainable antimicrobial stewardship; AMR surveillance; Antibiotic resistance.

KEY MESSAGES

- **A Tale of Two Pandemics:** The COVID-19 pandemic exacerbated AMR through antibiotic shortages, misuse, and weakened infection prevention measures.
- **Surveillance Gaps:** Limited laboratory capacities and reallocation of resources during the pandemic have severely hindered AMR monitoring, especially in low- and middle-income countries (LMICs).
- **Lessons from COVID-19:** Integrating AMS into pandemic preparedness requires universal access to diagnostics and antimicrobials, supported by effective stewardship practices.
- **One Health Approach:** Tackling AMR effectively requires cross-sector collaboration addressing human, animal, and environmental health.
- **Policy Priorities:** Invest in infection prevention, improve access, rationalise antimicrobial use, and ensure sustainable stewardship practices.
- **Global Collaboration:** Strengthening international partnerships and knowledge sharing is essential for effectively combating AMR.
- **Call to Action:** Leverage the lessons from COVID-19 to maintain antibiotic safety and build resilient global health systems.

La pandémie de COVID-19 a eu un impact complexe sur la pandémie silencieuse de la résistance aux antimicrobiens (RAM). Alors que l'augmentation de la mauvaise utilisation des antibiotiques et la perturbation des programmes de gestion des antimicrobiens ont exacerbé la RAM dans certains contextes, la sensibilisation accrue et l'amélioration des mesures de prévention des infections mises en œuvre pour contrôler le COVID-19 ont permis de tirer des enseignements précieux sur le maintien de ces pratiques dans la lutte contre la résistance aux antimicrobiens. Ce document met en lumière les enseignements tirés de la pandémie, tels que l'importance de l'accès aux antimicrobiens et le besoin urgent de programmes de gestion des antimicrobiens résilients et durables, intégrés dans la préparation à la pandémie, le renforcement des systèmes de prévention et de surveillance des infections, l'amélioration de l'accès et de l'utilisation des diagnostics et la promotion d'une approche « Une seule santé ». En tirant parti de ces enseignements, les décideurs politiques peuvent mettre en place des systèmes de santé plus résistants, maintenir l'efficacité des antimicrobiens et être mieux préparés aux futures pandémies, en particulier dans les pays en développement. Il est essentiel d'agir rapidement pour protéger la santé publique et lutter efficacement contre la résistance aux antimicrobiens.

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MOTS-CLÉS: *La résistance aux antimicrobiens (RAM); la gestion des antimicrobiens; COVID-19; la préparation à la pandémie; l' approche « Une seule santé »; la gestion durable des antimicrobiens; le surveillance de la RAM; la résistance aux antibiotiques.*

La pandemia de COVID-19 ha tenido un impacto complejo en la pandemia silenciosa de la resistencia a los antimicrobianos (RAM). Mientras que el aumento del uso indebido de antibióticos y la interrupción de los programas de administración de antimicrobianos exacerbaron la RAM en algunos entornos, la mayor concienciación y la mejora de las medidas de prevención de infecciones aplicadas para controlar la COVID-19 proporcionaron valiosas lecciones sobre el mantenimiento de estas prácticas en la lucha contra la RAM. Este informe destaca las lecciones aprendidas de la pandemia, como la importancia del acceso a los antimicrobianos y la necesidad urgente de programas de gestión de antimicrobianos resilientes y sostenibles integrados en la preparación para pandemias, el fortalecimiento de los sistemas de prevención y vigilancia de infecciones, la mejora del acceso y el uso de diagnósticos y la promoción de un enfoque de «Una salud». Al aprovechar estas lecciones, los responsables políticos pueden construir sistemas de salud más resilientes, mantener la eficacia de los antimicrobianos y estar mejor preparados para futuras pandemias, especialmente en los países en desarrollo. Es esencial actuar de inmediato para proteger la salud pública y combatir eficazmente la RAM.

PALABRAS CLAVES: *La resistencia a los antimicrobianos (RAM); la administración de antimicrobianos; COVID-19; la preparación para pandemias; el enfoque «Una salud»; la administración sostenible de antimicrobianos; la vigilancia de la RAM; la resistencia a los antibióticos.*

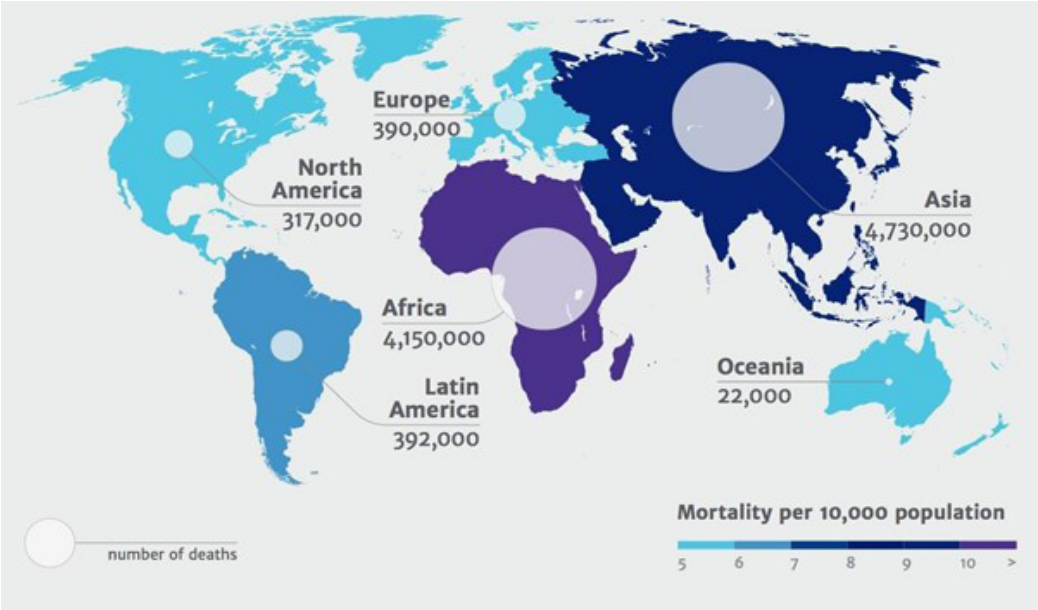
1. Introduction

1.1. Antimicrobial Resistance: Global Burden

Sir Alexander Fleming's warning during his Nobel Prize lecture in 1945 about the dangers of antimicrobial resistance (AMR) is now a reality that poses one of the most significant global health challenges of the twenty-first century. AMR occurs when microorganisms—bacteria, viruses, fungi, and parasites—evolve to withstand the effects of antimicrobial agents, rendering once-effective treatments ineffective.(1) This silent pandemic jeopardizes decades of advancements in medicine, from routine surgical procedures to lifesaving treatments for infections, placing millions of lives at risk. Without urgent intervention, antimicrobial resistance (AMR) could lead to 10 million deaths annually by 2050, disproportionately affecting low- and middle-income countries (LMICs) with fragile healthcare systems (Figure 1).(2) Alarmingly, every three seconds, someone dies from drug-resistant infections, underscoring the magnitude and urgency of the crisis.(1,2) Contributing factors such as the lack of access to clean water and poor sanitary conditions exacerbate the spread of AMR, particularly in LMICs. These conditions hinder effective infection prevention and control, compounding the challenge of combating AMR. Immediate global action is essential to address these interconnected issues and mitigate the devastating impact of AMR on public health.(3)

The global burden of AMR is already staggering. In 2021 alone, AMR was directly responsible for approximately 1.14 million deaths and associated with an additional 4.71 million deaths globally. (1,2) Regions such as Sub-Saharan Africa and South Asia bear the highest toll, reflecting the dual challenges of high disease prevalence and limited access to effective healthcare infrastructure. Emerging pathogens, such as methicillin-resistant *Staphylococcus aureus* (MRSA) and carbapenem-resistant Gram--negative bacteria, are particularly concerning due to their role

Figure 1. Deaths attributable to AMR every year by 2050 (Adopted from AMR Review Report) (2)



in severe, untreatable infections. These pathogens contribute to prolonged hospital stays, increased mortality, and significant economic strain on already burdened health systems.(4)

The One Health approach is central to addressing AMR. This holistic framework recognises the interconnectedness of human, animal, and environmental health and advocates for coordinated actions across sectors. For example, reducing the use of antibiotics in agriculture can help mitigate resistance in zoonotic pathogens, while environmental regulations can limit the release of antimicrobial residues.(5)

1.2. Antimicrobial Stewardship Framework

Antimicrobial Stewardship (AMS) is critical in addressing the global challenge of AMR, promoting responsible antimicrobial use across human, animal, and environmental health systems.(4) Guided by the One Health approach, AMS recognises the interconnectedness of these domains and the need to tackle AMR across all ecosystems, transcending human and animal boundaries to safeguard health and ecosystems alike.(5)

AMS focuses on the judicious use of antibiotics to optimise clinical outcomes, reduce resistance, and preserve the efficacy of existing drugs. Key strategies include prescribing antibiotics only when necessary, using the correct dose, and limiting treatment duration to what is clinically appropriate.(6) AMS teams are multidisciplinary, involving physicians, pharmacists, veterinarians, microbiologists, infection prevention specialists, public health experts, and environmental scientists.(7) Together, they implement targeted interventions across healthcare, community, animal, and environmental settings.(4,7)

In healthcare settings, AMS efforts include developing context-specific guidelines, de-escalation practices, and infection prevention measures to minimise unnecessary antibiotic use. Community-level programs promote public education, awareness campaigns, and vaccination initiatives to prevent infections and reduce reliance on antibiotics.(8) In animal health, AMS focuses on promoting responsible antibiotic use, restricting critical antimicrobials, and enhancing biosecurity measures to curb resistance.(8) Environmental AMS strategies aim to reduce antibiotic contamination in water, soil, and waste systems, limiting environmental pathways for resistance transmission. Education and capacity building underpin AMS initiatives, leveraging tools like virtual workshops, online courses, and mobile apps to train healthcare professionals, community members, and other stakeholders effectively.(7-8)

The One Health approach highlights the importance of global coordination, collaboration, and sustainable practices to unify AMS efforts, ensuring resilient systems capable of addressing health crises like COVID-19. By embedding AMS within this framework, shared responsibility across sectors is fostered, helping to mitigate AMR, protect health systems, and sustain ecosystems for future generations. Evidence-based AMS practices enhance patient care and reduce the risks associated with inappropriate antibiotic use.(8)

Global initiatives like the World Health Organization (WHO) AWaRe classification system, which categorises antibiotics into Access, Watch, and Reserve groups, have advanced AMS by encouraging prudent antibiotic use, particularly of last-resort medications. Beyond human healthcare, AMS has extended to veterinary and agricultural practices, recognising the broader impact of antibiotic use across interconnected health systems.(9)

Despite its vital role, AMS faces numerous challenges, particularly in LMICs, where limited resources, gaps in education, and weak surveillance hinder implementation. Strengthening AMS frameworks globally is imperative to extend the lifespan of existing antibiotics, support equitable access to effective treatments, and contribute to universal health coverage. As a cornerstone in combating AMR, AMS remains essential to safeguarding public health and mitigating the escalating threat of resistance.(9,10)

The AMS core elements serve as fundamental principles for promoting the responsible use of antibiotics across healthcare settings, communities, and animal health sectors. These elements focus on prescribing antibiotics only when necessary, using the correct dosage and shortest effective duration based on evidence. AMS involves reassessing treatment when culture results become available, supporting infection prevention and control, and addressing the source of infection to minimise unnecessary antibiotic use.(11)

Educating healthcare staff and fostering an interdisciplinary approach are critical to ensuring the success of AMS programs. Additionally, AMS emphasizes the importance of monitoring antimicrobial consumption and supporting surveillance systems to track AMR and healthcare-associated infections (HAIs). By adopting these core elements, AMS seeks to reduce the risks associated with inappropriate antibiotic use, safeguard public health, and preserve the efficacy of existing antimicrobials for future generations.(10,12)

1.3. COVID-19 and Antimicrobial Resistance Challenges

As of 25 November 2024, WHO reported a staggering 776,841,264 confirmed cases of COVID-19 worldwide, with a total death toll reaching 7,075,468.(13) This unprecedented global health crisis not only strained healthcare systems but also profoundly impacted antimicrobial resistance and stewardship. The pandemic created a unique context where healthcare systems focused heavily on managing the viral outbreak, leading to the deprioritization of AMS programs and infection prevention measures, which significantly weakened the ability to combat the escalating AMR crisis.(14)

A major consequence of the pandemic was the misuse of antibiotics. Despite COVID-19 being a viral illness, 37–75 percent of hospitalized COVID-19 patients were prescribed antibiotics, while bacterial co-infections were confirmed in only 8–16 percent of cases. This inappropriate prescribing accelerated the

emergence of multidrug-resistant organisms such as carbapenem-resistant *Acinetobacter baumannii* and *Candida auris*. Compounded by disrupted AMS activities, this overuse has contributed to a global surge in AMR.(15-16)

AMS activities such as monitoring prescribing behaviours, conducting audits, and providing feedback were disrupted or deprioritised during the pandemic. Social distancing further limited essential collaborations and education. The resultant "AMS fatigue" saw prescribers prioritise immediate pandemic-related challenges over rational antibiotic use.(16)

Moreover, AMR surveillance systems were overwhelmed by the demands of COVID-19 testing. Laboratories processed fewer resistance isolates, creating data gaps and delays, particularly in LMICs. Supply chain disruptions also exacerbated shortages of diagnostics and antimicrobials. This data highlights the urgent need to strengthen AMS frameworks by integrating pandemic preparedness strategies, prioritising evidence-based prescribing, and adapting lessons from COVID-19 to address AMR globally.(17-18)

2. Impact of COVID-19 on Antimicrobial Resistance and Stewardship

The COVID-19 pandemic has had profound implications for antimicrobial resistance and stewardship. As a global health crisis, it has disrupted AMS programs, strained healthcare systems, and exacerbated the inappropriate use of antimicrobials. It is pivotal to understand these impacts, detailing the critical lessons learned and the path forward for sustainable AMS. Figure 2 illustrates the interconnection between the COVID-19 pandemic and the silent pandemic of antimicrobial resistance, highlighting the compounded challenges faced globally.(18-19)

Figure 2. COVID-19 pandemic and antimicrobial resistance silent pandemic (19)

2.1. Increased Antimicrobial Misuse and Inappropriate Prescribing

The COVID-19 pandemic significantly amplified the global AMR crisis by increasing the misuse and inappropriate prescribing of antibiotics. This inappropriate use arose from clinical uncertainty, precautionary measures, and limited diagnostic capacity to distinguish bacterial from viral infections. One alarming consequence was the rise of multidrug-resistant organisms (MDROs) like carbapenem-resistant *Acinetobacter baumannii*, which caused severe hospital-acquired infections and resisted nearly all available antibiotics.(17) Similarly, *Candida auris*, a multidrug-resistant fungal pathogen, became a critical threat in overwhelmed intensive care units, its ability to persist on surfaces and resist standard antifungal treatments leading to outbreaks. Compounding this issue was widespread inappropriate antibiotic prescribing. Broad-spectrum antibiotics, such as azithromycin and ceftriaxone, were often used empirically to address undetected bacterial co-infections in critically ill COVID-19 patients.(17) Azithromycin, investigated for potential antiviral properties, saw excessive use, driving resistance in bacterial pathogens.(9) These challenges underline the urgent need for robust Antimicrobial Stewardship programs to guide evidence-based prescribing. Interventions such as rapid diagnostics, context-specific guidelines, and targeted education are critical to ensuring rational antibiotic use, safeguarding public health, and curbing the AMR crisis.(18)

2.2. Disruption of Antimicrobial Stewardship Practices

The COVID-19 pandemic profoundly disrupted antimicrobial stewardship programs, as healthcare systems reallocated resources to manage the crisis. AMS teams were left understaffed, and essential interventions such as audits, de-escalation protocols, and multidisciplinary rounds were deprioritised amidst the overwhelming focus on COVID-19 care. Healthcare workers faced unprecedented strain, further limiting the capacity to monitor and guide appropriate antibiotic use, which undermined efforts to combat antimicrobial resistance.(19)

Clinical uncertainty and limited diagnostic capacity often led to an increase in empirical antibiotic prescribing, exacerbating AMR. An evaluation of antibiotic prescribing adherence to the "Five Rights of Antibiotics" revealed significant shifts during the pandemic, including an increase in prescriptions without clear indications from 16 percent to 20 percent.(6)

These findings highlight the urgency of correlating antibiotic consumption with prescribing appropriateness to ensure effective stewardship. Additionally, AMS education and training initiatives were significantly curtailed, reducing opportunities to reinforce stewardship principles among clinicians during a critical time.(19-20)

The impact of COVID-19 has highlighted the debate between shorter and longer antibiotic durations. Shorter courses are effective for many respiratory infections, aligning with antimicrobial stewardship goals to reduce resistance and side effects.

However, during the pandemic, clinical uncertainty and a heightened focus on patient safety often led to longer antibiotic courses, particularly for severe or undiagnosed conditions. This highlights the need for accurate diagnostics, evidence-based prescribing, and a balanced approach to optimise outcomes while minimising unnecessary antibiotic use. (21)

2.3. Interruption of Infection Prevention and Control

The COVID-19 pandemic made evident the importance of good infection prevention and control (IPC) measures and basic water, sanitation and hygiene (WASH) services. Overcrowded hospitals, overwhelmed healthcare systems, and shortages of personal protective equipment (PPE) led to significant disruption in IPC practices. These disruptions created an environment conducive to the spread of multidrug-resistant organisms (MDROs), such as *Acinetobacter baumannii* and *Candida auris*.(10,23)

Hygiene practices, including hand hygiene and routine disinfection, were deprioritised in the face of unprecedented patient surges and staff fatigue. Healthcare workers, strained by mental and physical exhaustion, faced challenges in maintaining IPC standards. These gaps not only facilitated the transmission of healthcare-associated infections but also increased the reliance on antibiotics, further exacerbating the AMR crisis. The pandemic starkly exposed vulnerabilities in IPC systems, highlighting the fragile balance between crisis management and routine infection control efforts.(23)

2.4. Surveillance Challenges

The pandemic disrupted AMR surveillance systems worldwide. The increased demand for COVID-19 testing overwhelmed laboratory capacities, leading to a reduction in AMR monitoring. Laboratories prioritised SARS-CoV-2 (Severe Acute Respiratory Syndrome Coronavirus 2 – the strain of coronavirus responsible for COVID-19) diagnostics, resulting in delays in processing bacterial culture and sensitivity tests. This shift created data gaps, hindering efforts to track resistance patterns and guide AMS interventions. Low- and middle-income countries were disproportionately affected due to limited laboratory infrastructure and resources. Reporting delays and insufficient surveillance networks exacerbated the challenge of monitoring AMR trends in these regions. Strengthening AMR surveillance by integrating it with pandemic preparedness efforts is essential for global health security.(23)

2.5. Workforce Strain

The COVID-19 pandemic placed significant strain on the healthcare workforce, disrupting antimicrobial stewardship efforts across healthcare systems. Inappropriate antibiotic use without clinical justification emerged as a major concern, alongside a rise in healthcare-associated infections (HAIs).(22-23) Technology platforms and antibiotic reviews were widely recognised for their positive role in supporting AMS practices during the crisis.(24) The dissemination of reliable information was highlighted as a critical need, particularly as evidence-based guidelines were often overshadowed by misinformation from social media. Likewise, staying updated on resistance patterns and antibiotic prescribing trends was considered essential for effective AMS interventions. However, mental fatigue during the pandemic was reported to have adversely affected decision-making across the workforce.(25)

2.6. AMS Educational Challenges

The COVID-19 pandemic severely disrupted AMS educational initiatives. Social distancing measures halted traditional in-person training programs, significantly limiting opportunities for healthcare professionals to engage in stewardship education. (25)
The intense strain on clinicians during the crisis led to AMS fatigue, reducing their capacity and motivation to participate in educational activities, which highlighted vulnerabilities in AMS education systems, exposing a gap in providing healthcare workers with consistent, effective training during emergencies. The disruption not only impacted ongoing AMS practices but also hindered efforts to combat antimicrobial resistance effectively during a critical time.(25)

2.7. Sustainability and Resilient AMS

The COVID-19 pandemic severely impacted the sustainability and resilience of AMS frameworks, exposing critical weaknesses in global healthcare systems. Supply chain disruptions resulted in significant shortages of essential antibiotics and diagnostics, compromising the ability to manage infections effectively.

These shortages highlighted vulnerabilities in procurement and distribution systems, particularly in low-resource settings, where access to quality-assured antimicrobials was already limited. The pandemic placed additional strain on AMS implementation as resources were diverted to the COVID-19 response, deprioritising routine stewardship activities.

This disruption further weakened AMS efforts to combat AMR during a time when inappropriate antibiotic use was on the rise. The fragility of AMS systems during crises emphasised the urgent need for robust and sustainable frameworks capable of withstanding future public health emergencies. Without such measures, equitable access to antimicrobials and diagnostics is at risk, undermining global progress in addressing AMR.(26)

2.8. Supply Chain Disruptions

The COVID-19 pandemic severely disrupted global supply chains, causing significant shortages of essential antibiotics and medical supplies. Lockdowns, transportation restrictions, and surges in demand overwhelmed procurement systems, leaving healthcare facilities, particularly in LMICs, critically understocked.

These disruptions compromised infection management and increased the risk of antimicrobial resistance due to the reliance

on suboptimal or unavailable treatments. The strain on supply chains highlighted the fragility of existing systems and the lack of preparedness to handle crises. Without timely access to quality-assured antimicrobials and diagnostics, healthcare systems struggled to maintain effective antimicrobial stewardship efforts, exacerbating the global AMR crisis. The pandemic underscored the urgent need for robust and resilient supply chain infrastructures to prevent similar consequences in future public health emergencies.(27)

2.9. LMIC-Specific Challenges

LMICs faced unique challenges in AMS implementation during the pandemic. Weak regulatory frameworks allowed over-the--counter sales of antibiotics, contributing to misuse. Limited access to diagnostics further compounded the problem, as clinicians relied on empirical prescribing in the absence of confirmatory tests.

Supply chain disruptions in LMICs exacerbated antimicrobial misuse. Many hospitals experienced stockouts of narrow-spectrum antibiotics, forcing reliance on broad-spectrum alternatives. This practice not only increased resistance but also widened the equity gap in healthcare access.(10)

3. Lessons Learned from the COVID-19 Pandemic

3.1. Lesson 1: Embedding equitable antimicrobial stewardship into local, national, and global pandemic response plans improves antibiotic prescribing and infection management

The COVID-19 pandemic highlighted the critical need to integrate antimicrobial stewardship into local, national and global emergency response plans. Key lessons learned include:

1. **Necessity of AMS Frameworks:** Robust AMS frameworks are vital to prevent antibiotic misuse, combat antimicrobial resistance, and safeguard public health by integrating rational antimicrobial use into pandemic preparedness strategies.

2. **Prioritising AMS in Response Plans:** Pandemic response plans should prioritise AMS by defining multidisciplinary roles, allocating resources, and developing evidence-based antimicrobial use guidelines for empirical and targeted antibiotic therapy during crises.(28)

3. **Enhanced Surveillance Systems:** Real-time surveillance systems must be enhanced to monitor antimicrobial consumption and resistance patterns, with special attention to high-risk areas like intensive care and emergency units. This ensures timely and accurate data to inform AMS practices.(29-30)

4. **Training and Upskilling:** AMS frameworks should include adapted training programs to upskill healthcare professionals in evidence-based antimicrobial prescribing during crises. Leveraging technology, such as virtual meetings, antibiotic rounds, reviews, and audits, can help sustain AMS practices.

5. **Structured AMS Programmes:** Structured AMS programmes with timely review and decision-making are essential. The "48-hour review" model—stop, switch, continue, narrow spectrum, or transition to outpatient therapy—remains a cornerstone in secondary care AMS.

6. **Consistency in Prescribing Practices:** Variations in prescribing highlight the need for appropriate antibiotic prescribing. Efforts should focus on aligning practices with updated guidelines, real-time antibiogram data, and resistance trend monitoring to ensure optimal use.

7. **Antibiotic Safety:** Ensure antibiotics are prescribed appropriately, with the right drug, dose, and duration, to minimise resistance and optimise patient outcomes.

8. **Equitable Access:** Ensuring equitable access to antibiotics and diagnostics and stewardship resources is critical to address disparities in pandemic response effectiveness. This includes making sure that all communities, regardless of socioeconomic status, have access to necessary treatments and AMS resources.

3.2. Lesson 2: Enhanced AMR surveillance and collaboration ensure effective global pandemic response and control

The COVID-19 pandemic underscored the necessity for robust antimicrobial resistance surveillance systems that remain effective during emergencies. Key lessons learned include:

1. **Real-Time Data Sharing:** Innovations in real-time data sharing, which were crucial during the pandemic, provide a model for enhancing AMR surveillance. Continuous monitoring of AMR trends, even during public health crises, is essential to mitigate the threat of emerging resistant pathogens.(27)

2. **Leveraging Technology:** Utilizing technology for real-time data collection and analysis is a significant lesson from the pandemic. Digital platforms, integrated data dashboards, and automated reporting systems ensure timely insights that inform evidence-based interventions. These technologies should be adapted for AMR surveillance to provide rapid, actionable data on resistance patterns and antimicrobial use.

3. **International Collaboration:** Effective tracking of AMR trends requires international collaboration. Linking surveillance networks, such as the Global Antimicrobial Resistance and Use Surveillance System (GLASS), promotes data sharing, standardization, and coordinated responses. Partnerships between high-income and LMICs are particularly important, as LMICs often face challenges in maintaining consistent surveillance due to resource constraints.(28)

4. **Building Resilience:** By fostering global cooperation and adopting advanced surveillance technologies, health systems can build resilience against AMR. Strengthened surveillance systems support local and national efforts and contribute to a unified global strategy for combating AMR.

3.3. Lesson 3: Enhanced diagnostic infrastructure and investment improve availability, efficiency, and patient outcomes

The COVID-19 pandemic highlighted the critical importance of robust diagnostic infrastructure in combating antimicrobial resistance. Key lessons learned include:

1. **Multidisciplinary Collaboration:** Effective diagnostic practices and antimicrobial stewardship require collaboration among microbiologists, clinical teams, and infection control specialists. This multidisciplinary approach ensures comprehensive and accurate diagnostics.(29,30)

2. **Investment in Diagnostics:** The pandemic highlighted the unchecked growth of drug-resistant infections, emphasizing the need for governments to invest in pandemic preparedness. Such investments can yield significant health and economic benefits, particularly in developing countries.(31-32)

3. **Rapid Diagnostic Tools:** Expanding diagnostic capabilities, especially through point-of-care testing (POCT), is crucial for distinguishing bacterial from viral infections. This minimizes inappropriate antibiotic use, reduces delays, and improves patient outcomes.(31)

4. **Evidence-Based Decision Making:** Integrating antibiograms and sharing resistance patterns across teams enhances decision--making. Microbiologists provide insights into resistance trends, while infection control teams ensure the practical application of guidelines.(33)

5. **Access to Resources:** Ensuring that healthcare workers have access to the latest resources and guidelines tailored to emerging resistance trends is essential for effective diagnostics.

6. **Availability of Medicines and Equity:** Investments in diagnostics should be paired with ensuring equitable availability of essential antimicrobials, especially in LMICs, to support universal health care for all.

3.4. Lesson 4: Rational antibiotic use prevents resistance, ensures effective treatment and safety

The COVID-19 pandemic highlighted the critical need to promote rational antibiotic use to minimize antimicrobial resistance. Key lessons learned include:

1. **Adherence to Evidence-Based Guidelines:** It is essential to follow evidence-based guidelines for antibiotic prescribing. This ensures that antibiotics are used appropriately and only when necessary.

2. **Leveraging Diagnostics:** Utilizing diagnostic tools to distinguish between bacterial and viral infections is crucial. Accurate diagnostics help in making informed decisions about antibiotic use, reducing unnecessary prescriptions.

3. **Public Education Campaigns:** Raising awareness about the risks of AMR and the responsible use of antibiotics through public education campaigns is vital. These initiatives should target communities, emphasizing the dangers of self-medication and the importance of completing prescribed antibiotic courses.

4. **Healthcare Professional Training:** Continuous training for healthcare professionals on rational antibiotic prescribing is necessary. This includes updating them on the latest guidelines, resistance trends, and the use of tools like antibiograms.

5. **Updated Prescribing Tools:** Providing healthcare professionals with updated prescribing tools, such as antibiograms and resistance trend data, supports consistent and rational antibiotic use across healthcare systems.

6. **Equitable Access to Medicines:** Promoting rational antibiotic use must ensure equitable access to essential medicines globally, particularly in underserved regions. This is crucial to address disparities in healthcare and ensure that all populations benefit from effective treatments.

7. **Collaboration:** Healthcare professional training should include collaborative platforms for sharing resistance trends, best practices, and updated guidelines to ensure consistent antibiotic prescribing.

3.5. Lesson 5: One Health approach integrates human, animal, environmental health for pandemic resilience

The COVID-19 pandemic highlighted the critical interconnectedness of human, animal, and environmental health, emphasizing the need for a comprehensive One Health approach to effectively tackle antimicrobial resistance. Key lessons learned include:

1. **Interconnected Health Systems:** The pandemic revealed vulnerabilities in global health systems, such as unregulated antibiotic use in agriculture and inadequate waste management from healthcare facilities, which contribute to environmental contamination and the spread of resistant pathogens.

2. **Cross-Sector Collaboration:** Strengthening collaborations across human healthcare, veterinary medicine, and environmental management is crucial for a unified response to AMR. Integrating efforts across these sectors can foster a coordinated approach to surveillance, stewardship, and intervention strategies.

3. **Data Sharing and Policy Improvement:** Sharing data on resistance patterns in the different sectors, improving antimicrobial use policies in agriculture, and enforcing regulations on pharmaceutical waste disposal are essential components of a One Health strategy.

4. **Investment in Infrastructure:** The pandemic highlighted the importance of investing in infrastructure and resources for One Health programs, especially in low- and middle-income coun-

tries. This includes building capacity for surveillance, diagnostics, and stewardship across all sectors.

5. **Multidisciplinary Teams:** Multidisciplinary teams involving microbiologists, infectious disease specialists, veterinarians, and environmental scientists should collaborate to develop context-specific solutions. This approach ensures that all aspects of AMR are addressed comprehensively.

6. **Holistic and Sustainable Response:** By adopting a One Health approach, policymakers can ensure a holistic and sustainable response to AMR, safeguarding public health, animal welfare, and environmental integrity.

7. **Equitable Distribution of Resources:** A One Health strategy must prioritize equitable distribution of resources, including diagnostics and medicines, across sectors and regions to ensure inclusivity in addressing AMR. This ensures that all communities, especially those in underserved regions, have access to necessary tools and treatments.

8. **Strengthen Cross-Sector Collaboration:** Cross-sector collaboration is crucial for an integrated response to AMR, fostering partnerships across healthcare, veterinary medicine, and environmental management to develop comprehensive solutions.

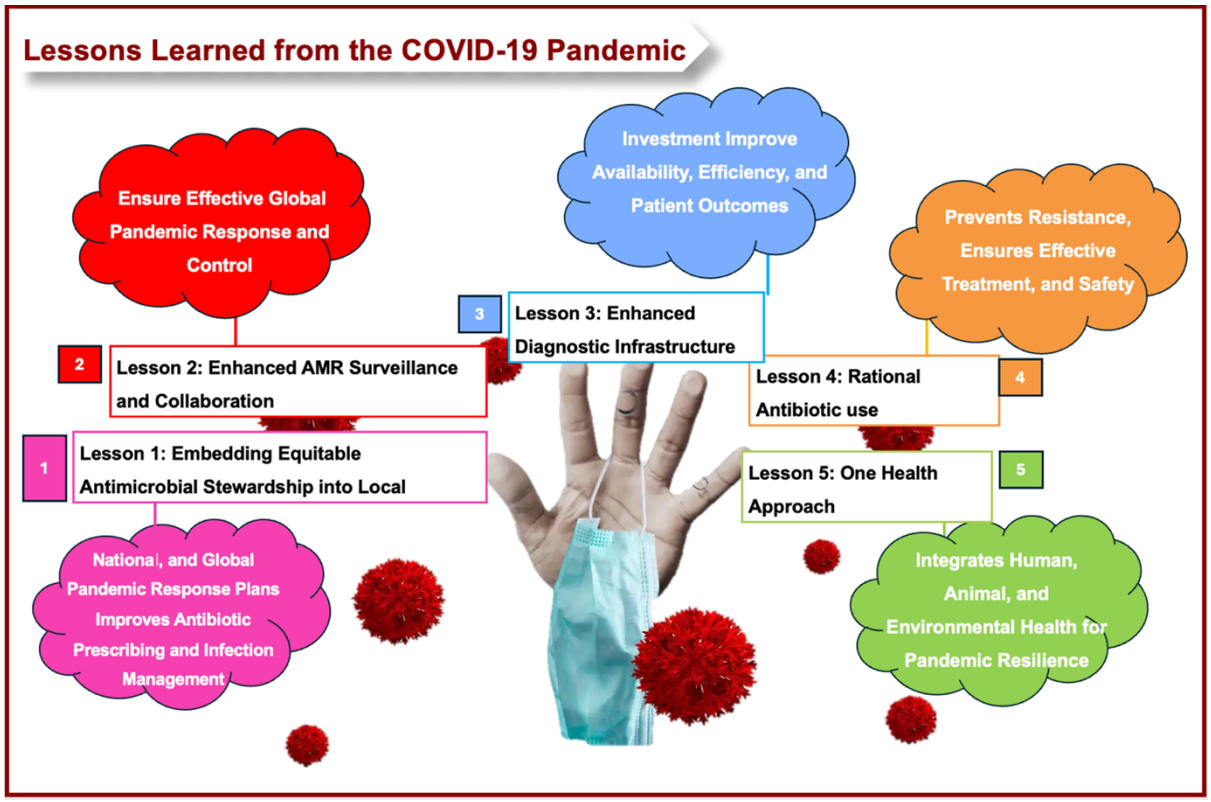
4. Policy Recommendations

4.1. Addressing Sustainable Access Challenges

The COVID-19 pandemic exposed significant challenges in accessing antimicrobials, diagnostics, and vaccines, particularly in LMICs. While ensuring equitable access to these resources is crucial, balancing accessibility with the need to mitigate antimicrobial misuse remains a critical challenge. A comprehensive approach is required to address the sustainable access challenge, ensuring both availability and effective stewardship. Investments in robust supply chains are essential to ensure uninterrupted access to quality-assured antimicrobials, diagnostics, and vaccines. This includes diversifying manufacturing hubs and reducing reliance on single suppliers in LMICs to minimise disruptions during global crises. Mechanisms to maintain the availability of essential medicines while ensuring affordability and accessibility must also be prioritised.

Effective AMS strategies must be integrated into sustainable access programmes. The pandemic underscored the importance of diagnostics in guiding antimicrobial use and vaccines in reducing infection burdens. Addressing barriers to access, such as cost and infrastructure limitations, requires international collaboration to subsidise advanced diagnostic tools and facilitate

Figure 3. Summary of lessons learned from the COVID-19 pandemic (Photo credit: Dr. Rasha Abdelsalam Elshenawy)



vaccine deployment in resource-limited settings. Effective regulatory frameworks are vital to prevent over-the-counter sales and inappropriate use of antimicrobials. Collaboration between governments, global health organisations, and industry stakeholders is essential to establish and enforce policies that promote responsible access and prevent misuse, particularly in LMICs.

A One Health approach ensures that sustainable access efforts extend beyond human health to include veterinary and agricultural sectors. Addressing antimicrobial use in animals and ensuring access to alternatives, such as vaccines and biosecurity measures, are essential to prevent spillover effects and support sustainable access for all.

4.2. Advancing Sustainable Antimicrobial Stewardship in Global Health

The COVID-19 pandemic exposed significant gaps in antimicrobial stewardship, highlighting its critical role in global health and pandemic preparedness. Sustainable AMS is essential to maintaining the long-term effectiveness of antimicrobials, combating antimicrobial resistance, and building resilient healthcare systems capable of responding to future health crises.

To achieve sustainable AMS, stewardship principles must be embedded in global and national response frameworks. This includes developing evidence-based guidelines for antimicrobial use during emergencies, ensuring that AMS strategies are scalable and adaptable to diverse healthcare challenges, and prioritising real-time data collection on antimicrobial use and resistance trends. These actions enable timely, informed decision-making, particularly in high-risk settings such as intensive care units. Investments in capacity-building—such as training healthcare professionals, enhancing laboratory infrastructure, and strengthening surveillance systems—are vital for effective AMS implementation. Sustained funding and international collaboration are also crucial to address resource gaps in low- and middle-income countries, where limited infrastructure hinders AMS efforts.

By prioritising sustainable AMS as a cornerstone of global health, policymakers can enhance healthcare systems' resilience, preserve the efficacy of antimicrobials for future generations, and ensure robust, coordinated responses to AMR in both routine and crisis scenarios. Immediate action is essential to protect public health and mitigate the growing threat of AMR.

4.3. Enhance Surveillance and Diagnostics

The COVID-19 pandemic highlighted critical gaps in AMR surveillance and stewardship, particularly in LMICs. One of the key lessons is the urgent need to strengthen surveillance systems by addressing issues such as the lack of standardisation in laboratory reporting, insufficient access to supplies, and interrupted diagnostic supply chains. The absence of technical expertise in many LMIC laboratories further limits their ability to effectively monitor AMR trends.

The pandemic highlighted the transformative potential of point-of-care testing (POCT) technologies in overcoming diagnostic bottlenecks. POCT enables rapid, accurate identification of infections, supporting evidence-based antimicrobial prescribing and minimising unnecessary antibiotic use. This technology proved invaluable during the COVID-19 crisis and should be integrated into future AMR surveillance frameworks. Linking LMIC laboratories to global networks, such as the Global Antimicrobial Resistance and Use Surveillance System (GLASS) report, is essential for a cohesive AMR response. GLASS facilitates data sharing, standardises methodologies, and provides technical support, enabling LMICs to contribute to and benefit from global surveillance efforts. The pandemic also highlighted the need for robust stewardship practices, addressing challenges such as unregulated antimicrobial sales and weak pharmacovigilance systems. Strengthening surveillance through GLASS integration, POCT adoption, workforce training, and community engagement is essential for building resilient AMR management systems for future health crises.

4.4. Enforcing Regulatory Measures

The COVID-19 pandemic exposed the critical need for robust regulatory frameworks to address AMR. Weak regulation of antimicrobial prescribing and dispensing practices contributed to inappropriate usage during the crisis. In many LMICs, over-the--counter sales of antibiotics without a prescription exacerbated the problem, undermining AMS efforts. Stricter enforcement of prescribing guidelines is essential to ensure antibiotics are used only when clinically indicated, reducing the risk of resistance.

The pandemic also highlighted the overlooked role of antimicrobial use in agriculture and veterinary practices in driving AMR. The lack of effective policies regulating antibiotic use in animal husbandry has resulted in the widespread misuse of antimicrobials for growth promotion and disease prevention in livestock. These practices have significant spillover effects, increasing resistance in both animal and human populations. Establishing and enforcing regulations to restrict the use of medically important antimicrobials in agriculture is critical to mitigating this threat. Stronger governance mechanisms, including regulatory oversight, routine monitoring, and stringent penalties for non--compliance, are needed to enforce these measures. Collaboration between health, agricultural, and environmental sectors is vital to develop and implement these policies effectively, aligning with the One Health approach. Such regulatory interventions are essential for sustainable AMR containment and global health security.

4.5. Promote Education and Awareness

The COVID-19 pandemic highlighted the importance of education and awareness in combating antimicrobial resistance. It revealed significant gaps in knowledge and practice, highlighting the need to integrate antimicrobial stewardship training into medical and healthcare curricula. Regularly updating these cur-

ricula to reflect emerging threats and advancements ensures that future professionals are equipped to address evolving AMR challenges. Adaptive learning approaches, such as webinars, interactive sessions, case-based learning, and online modules, cater to diverse educational needs and environments.

Workforce training must be prioritised, offering real-time educational opportunities like antibiotic ward rounds, feedback on prescribing practices, and sharing AMR survivor stories to personalise the impact of resistance. Role models in AMR surveillance and One Health approaches, including environmental and veterinary sectors, can inspire best practices and foster interdisciplinary collaboration.

Community engagement is equally crucial. Public awareness campaigns should be conducted in plain language, tailored to local and cultural contexts, and offered in multiple languages for national and international reach.

These initiatives should emphasise the risks of AMR and the importance of stewardship. Involving community leaders, healthcare professionals, and educators can amplify impact and promote shared responsibility in AMR prevention. Sustained efforts in education and awareness are key to strengthening AMS, enhancing global preparedness, and fostering a culture of responsible antimicrobial use.

4.6. Advancing Research and Development

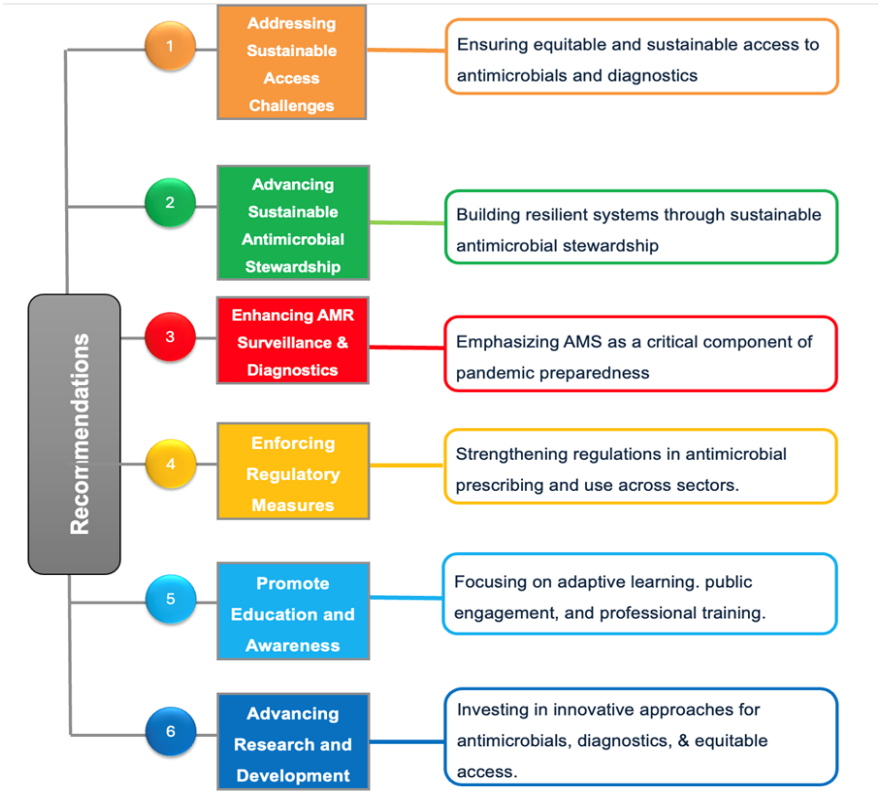
The COVID-19 pandemic highlighted the critical need for robust research and development (R&D) to confront AMR. Funding innovation in antimicrobials, vaccines, and diagnostics is essential to address current gaps and future threats. Special emphasis must be placed on ensuring equitable access to these advancements, particularly in developing countries, where disparities in healthcare resources hinder AMR containment.

Adopting innovative approaches in antibiotic research is vital. Combining traditional methods with digital tools facilitates data collection, analysis, and dissemination. Mobile-integrated research tools can be employed for surveys and interviews, enhancing accessibility and efficiency. QR codes and other digital methods can help engage broader healthcare workforces, improving the integration of diverse perspectives in research.

The pandemic also emphasized the importance of leveraging virtual and digital platforms for communication with research populations. Tools like video conferencing and online collaboration platforms allow researchers to maintain momentum and broaden their reach, even during global crises.

To amplify the impact of the research, diverse communication channels must be used. Blogs, community posts, correspondence research papers, visual abstracts, and infographics effectively engage different audiences. Such multi-faceted dissemination strategies ensure findings are accessible and actionable, fostering collaboration and innovation in the fight against AMR.

Figure 4. Policy Recommendations: Lessons from COVID-19 - Strengthening Antimicrobial Stewardship Before and During Pandemics (Photo Credit: Dr. Rasha Abdelsalam Elshenawy)



5. Conclusion

The COVID-19 pandemic has highlighted the urgent need to prioritise AMR as a global health challenge. To build resilient healthcare systems capable of addressing AMR and future crises, sustainable AMS frameworks must be informed by the lessons learned. Key priorities include integrating AMS into pandemic preparedness through evidence-based guidelines, enhancing diagnostics and surveillance to monitor AMR trends, and ensuring rational antimicrobial use to preserve the effectiveness of antibiotics.

Equitable access to quality-assured antimicrobials, diagnostics, and vaccines is vital, particularly in LMICs. Strengthening antimicrobial stewardship in these settings requires targeted policies, investments in infrastructure, regulatory reforms, and capacity-building initiatives. Expanding access to essential resources, promoting rational prescribing, and increasing public awareness are crucial steps toward combating AMR in resource-limited contexts.

To mitigate the long-term impact of the AMR pandemic, healthcare systems must prioritise sustainable AMS efforts, strengthen IPC, address workforce challenges, and ensure access to antimicrobials, diagnostics, and vaccination. By incorporating these strategies, global health stakeholders can establish robust AMS frameworks that safeguard public health against both current and future threats.

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