Lessons from COVID-19 to manage infectious diseases in low-income and middle-income countries 2

How can lessons from the COVID-19 pandemic enhance antimicrobial resistance surveillance and stewardship?

Kamini Walia, Marc Mendelson, Gagandeep Kang*, Ramasubramanian Venkatasubramanian*, Rina Sinha*, Sonam Vijay*, Balaji Veeraraghavan, Buddha Basnyat, Camilla Rodrigues, Nitin Bansal, Pallab Ray, Purva Mathur, Ram Gopalakrishnan, Vinod C Ohri*

COVID-19 demanded urgent and immediate global attention, during which other public health crises such as antimicrobial resistance (AMR) increased silently, undermining patient safety and the life-saving ability of several antimicrobials. In 2019, WHO declared AMR a top ten global public health threat facing humanity, with misuse and overuse of antimicrobials as the main drivers in the development of antimicrobial-resistant pathogens. AMR is steadily on the rise, especially in low-income and middle-income countries across south Asia, South America, and Africa. Extraordinary circumstances often demand an extraordinary response as did the COVID-19 pandemic, underscoring the fragility of health systems across the world and forcing governments and global agencies to think creatively. The key strategies that helped to contain the increasing SARS-CoV-2 infections included a focus on centralised governance with localised implementation, evidence-based risk communication and community engagement, use of technological methods for tracking and accountability, extensive expansion of access to diagnostics, and a global adult vaccination programme. The extensive and indiscriminate use of antimicrobials to treat patients, particularly in the early phase of the pandemic, have adversely affected AMR stewardship practices. However, there were important lessons learnt during the pandemic, which can be leveraged to strengthen surveillance and stewardship, and revitalise efforts to address the AMR crisis.

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See **Comment** page 890

This is the second in a **Series** of three papers on lessons from COVID-19 to manage infectious diseases in low-income and middle-income countries. All papers in the Series are available at www.thelancet.com/series/LMICs-lessons-from-COVID-19

*Contributed equally

Division of Epidemiology and Communicable Diseases, Indian Council of Medical Research, New Delhi 110029, India (K Walia PhD, S Vijay PhD, V C Ohri MD)**; Division of Infectious Diseases and HIV Medicine, Department of Medicine, Groote Schuur Hospital, University of Cape Town, Cape Town, South Africa** (Prof M Mendelson PhD)**; Department of Clinical Microbiology, Christian Medical College, Vellore, India** (G Kang MD PhD)**; Department of Infectious Diseases, Apollo Hospitals, Chennai, India** (R Venkatasubramanian MD, R Gopalakrishnan MD)**; World Health Organization, Country Office for India, New Delhi, India** (R Sinha MA)**; Christian Medical College Vellore, Vellore, India** (B Veeraraghavan MD)**; Oxford University Clinical Research Unit, Patan Academy of Health Sciences, Kathmandu, Nepal** (B Basnyat MD)**; Department of Microbiology, PD Hinduja Hospital, Mumbai, Maharashtra, India** (C Rodrigues MD)**; Division of Infectious Diseases, Rajiv Gandhi Cancer Institute and Research Centre, New Delhi, India** (N Bansal MD)**; Department of Medical**

Introduction

The COVID-19 pandemic presented an unprecedented challenge and worsened existing health threats, such as antimicrobial resistance (AMR).[1] The pandemic thrived on the shortcomings of global health systems to exacerbate socioeconomic inequalities.[2] Yet, the pandemic also served as a catalyst for much needed transformation by pushing the agendas of governments and policy makers to introduce a rapid health system overhaul. As a result, the frameworks and systems created at governance, policy, and institutional levels can now provide a strong foundation for addressing other public health priorities. AMR is one such area, which is now approaching alarming proportions, especially in low-income and middle-income countries (LMICs). In 2019, AMR claimed 4·95 million lives, 1·27 million as a direct result of resistance, with the highest death rates reported from sub-Saharan Africa and south Asia.[3] The deprioritisation of AMR containment efforts at all levels of health care during COVID-19 is expected to adversely affect AMR containment. AMR and COVID-19 have a complex relationship and, although the effects of COVID-19 on AMR remain unexplored at a global level, the COVID-19 crisis has had several successes that can be applied to reimagine the AMR response. In this Series paper we outline strategies that we believe could be implemented to strengthen AMR surveillance and stewardship initiatives.

COVID-19 response in LMICs

The novelty of SARS-CoV-2 and the many unknowns about its severity, pathogenesis, and patterns of spread necessitated flexible strategies in tandem with emerging evidence relating to modes of transmission, testing, tracking, and treatment. Although there was

Key messages

- Antimicrobial resistance (AMR) is steadily rising globally, especially in low-income and middle-income countries (LMICs)
- Critical gaps still exist in AMR surveillance and stewardship activities that have hindered progress in the containment of AMR
- The necessary focus on and investment in AMR containment strategies in LMICs, although lacking to start with, were further deprioritised during the COVID-19 pandemic
- Key strategies such as effective governance practices, diagnostics innovations, focus on vaccination programmes, digitisation, and community engagement acted as important pillars leading to COVID-19 management in LMICs
- Frameworks and strategies used for COVID-19 containment provide critical lessons to strengthen AMR surveillance and stewardship
- When deciding on national commitments for tackling AMR, LMICs should aspire to build a cohesive and enforceable response while considering the local context

Microbiology, Postgraduate Institute of Medical Education and Research, Chandigarh, India (P Ray MD); Department of Laboratory Medicine, Jai Prakash Narayan Apex Trauma Center, All India Institute of Medical Sciences, New Delhi, India (P Mathur MD)

Correspondence to: Dr Kamini Walia, Division of Epidemiology and Communicable Diseases, Indian Council of Medical Research, Ansari Nagar, New Delhi 110029, India
waliakamini@yahoo.co.in

Panel 1: Key features of COVID-19 management

- Top-down policies with local implementation strategies
- Increased diagnostic capacity
- Scaling up capacity for genomic surveillance to characterise new variants and a tailored response
- Manufacturing and innovation in vaccine development and large adaptive trial platforms for testing therapeutics
- Regulatory processes for rapid approvals
- Digital dashboards to track infections and vaccinations in real time

considerable diversity in how different countries and territories responded to COVID-19, the top-down governance structure was a common theme across almost all countries. Working groups were established to streamline and enable swift decision making on treatment, research, communication, logistics, and workforce while these decisions were implemented by emergency response groups. Following initial gaps in alignment across different groups of governments and the scientific community, these mechanisms harmonised diagnostic and vaccine availability, surveillance, treatment, and containment strategies to ensure optimal use of available resources (panel 1). Governments in several LMICs recognised the shortages of personal protective equipment, diagnostics, and ventilators[4] and were able to rapidly scale up production. Although there were successes, there were also short-term failures across countries as large waves of infection early in the pandemic saw rampant and inappropriate use of antibiotics, steroids, and traditional medicines; inconsistencies in communication to the public and other stakeholders; stigmatisation of health workers and COVID-19 patients; and shortages in hospital equipment, drugs, oxygen supplies, and testing kits.

An effective response to COVID-19 necessitated an immediate and large upgrade of health infrastructure and more specifically early and accurate diagnostic capacity. Enhanced testing programmes provided proxy real-time estimates of incidence although the true number of cases relative to those that were virologically confirmed was generally at least an order of magnitude greater. However, even this proxy gave countries the opportunity to plan for number of tests needed, hospital admissions, oxygen supply, and strategies to interrupt the chain of transmission. LMICs in Africa and southeast Asia faced major challenges in confirming diagnoses of SARS-CoV-2 infection because of a shortage of testing facilities, laboratory reagents, and test kits.[5] Following initial setbacks, diagnostic expansion was rapid with multiple providers establishing manufacturing capacity. In India, the network of laboratories undertaking COVID-19 tests increased over a 4-month period from less than 100 to approximately 4000 laboratories providing high throughput testing with quick turnaround times.

South Africa, an upper-middle-income country, became a world leader in genomic surveillance of COVID-19[6] and the first to identify the beta and omicron variants.[7,8] The identification of the variants was the result of the groundwork laid for tackling the HIV epidemic in South Africa over the previous two decades. Being prepared for pandemics with tools such as whole-genome sequencing can serve as early warning systems and play a crucial role in mitigation and control efforts. Genomic surveillance was expanded globally including in countries such as India and Nigeria that did not have previous large-scale pathogen platforms.[9] The availability of global sharing and analysis platforms such as the Global Initiative on Sharing All Influenza Data, and Nextstrain allowed researchers to classify and place their strains in a global context more rapidly and at an unprecedented scale.[10–12]

In the absence of an understanding of pathogenesis, potential therapies were studied in vitro and in small-scale clinical trials, providing early recommendations to health-care practitioners and governments. The robust evaluation of potential therapies was restricted in LMICs. As a respiratory pathogen overlapping in its clinical presentation with influenza-like illness, exacerbations of existing chronic respiratory illnesses, and pneumonia, SARS-CoV-2 drove inappropriate antibiotic use at community and hospital settings. Despite approximately 4·9% and 16·0% of patients having a proven bacterial co-infection at the time of presentation to hospital and during hospital stay, respectively,[13] 37% received one antibiotic[14] and a few hospitals reportedly administered more than three antibiotics to hospitalised patients with COVID-19.[15] The COVID-19 pandemic negatively affected antimicrobial stewardship across Indian hospitals (figure 1) on account of reallocation of workforce to prolonged emergency duties, understaffing, poor glove hygiene, and a reactive response to antibiotic use in intensive care units. Poor glove hygiene and a reflex response to antibiotic usage in intensive care units contributed to outbreaks of carbapenem-resistant *Acinetobacter baumannii* and *Candida auris*, which were not witnessed previously in participating hospitals. Large adaptive trial platforms for novel, existing (eg, azithromycin), and repurposed therapeutics (eg, hydroxychloroquine) to treat COVID-19 provided an evidence base for demonstrating the inefficacy of these antimicrobials in treating COVID-19.[16] Infection control in the early stages of COVID-19 spread in LMICs was oriented more towards protecting health workers due to fear of transmission rather than infection control among patients. There was also ambiguity on infection prevention practices due to routine universal glove use during all aspects of patient care, which caused confusion about how to perform optimal hand hygiene practices.[15,17]

The COVID-19 pandemic witnessed phenomenal speeds in vaccine development, with vaccine candidate designs made on the basis of previous studies of mRNA and other platforms. Vaccine development began in February, 2020, and vaccines became available for use in high-income countries (HICs) in December, 2020, and in LMICs soon after. Sadly, mRNA vaccines were mainly used in HICs, and access in LMICs to a full range of vaccine platforms was scarce and late. However, companies such as AstraZeneca committed to low pricing during the pandemic to ensure affordability and accessibility,[18] and their adenovirus vectored vaccine became one of the most widely used. Additionally, vaccine manufacturers in India, Cuba, and China showed that they had the ability to scale up manufacturing of vaccines, with all countries relying on locally produced vaccines to protect their populations.[19] With high rates of vaccination, there was less burden on the health-care systems in LMICs in 2022 than at the start of the pandemic.[20,21]

In a rapidly unfolding crisis with evolving scientific evidence, the pandemic saw tacit recognition of the fact that risk communication and community engagement would be important pillars for an effective response. The timely and impressive response by global research and development laboratories and regulators fast-tracked the progress of diagnostics, vaccines, and therapeutics. Unfortunately, the old experiences of non-equitable global distribution, weak governance of public health systems operations and inadequate funding availability, human resource shortages, broken supply chains, inadequate laboratory capacity and poor implementation of infection control practices, and market dynamics leaning towards HICs once again manifested during the pandemic.[22] Overall, the pandemic response capacity almost everywhere was inadequate, more so in LMICs. Although HICs claimed equity, little was put into practice.[23] The potential to utilise digital health tools for improving accountability, monitoring and evaluation, and access to health care remained underutilised.

Antimicrobial resistance containment, a formidable challenge in LMICs

AMR is a quintessential One Health issue, rooted at the human–animal–environment interface.[24] Resistance genes are found inmicroorganisms associated with humans, animals, and the environment, and spread effortlessly between species and locations.[25] Considering the multitude of challenges that make containment of AMR a formidable challenge, addressing the threat of AMR would therefore require a holistic and collaborative effort to ensure that efforts in one domain are not weakened by neglect in another (panel 2). To achieve this, the One Health approach needs to be reviewed to map barriers to facilitate collaboration across all relevant stakeholders and sectors.

Insights gathered from surveillance help to prioritise resource allocation and are fundamental to initiating and sustaining AMR control programmes. Spurred by the 2010 WHO, World Organisation for Animal Health, and The Food and Agriculture Organization tripartite collaboration, the WHO Global Antimicrobial Resistance and Use Surveillance System and antimicrobial usage (AMU) surveillance began in 2015, and reported 2019 AMR data from 24 803 surveillance sites in 70 countries. However, only 15 countries reported AMU data. In its fourth cycle, the WHO Global Antimicrobial Resistance and Use

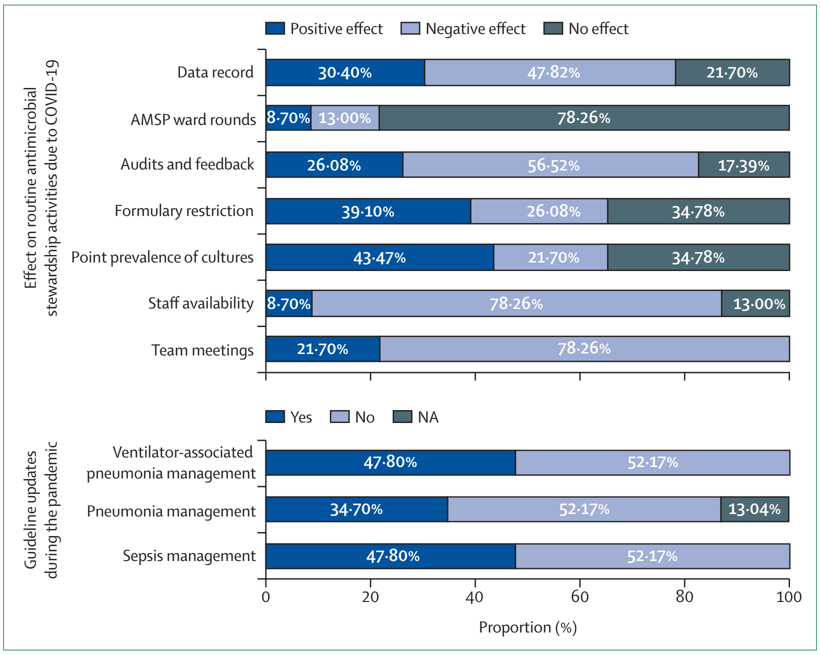

Figure 1: **The effect of COVID-19 on the practice of antimicrobial stewardship in Indian hospitals**
A total of 23 tertiary care hospitals (12 public sector and 11 private sector), which are already part of the Indian Council of Medical Research Antimicrobial Stewardship Program (15 hospitals), participated in the survey to assess the effects of the COVID-19 pandemic on practices of antimicrobial stewardship (AMS). 78% of hospitals reported non-availability of staff for AMS work, specifically affecting data recording and implementation of prescription audits. These staff were seconded to COVID-19 wards and intensive care units, which affected routine ongoing activity of AMS. 78% of hospitals also reported reduced AMSP team meetings. The survey assessed the challenges of understaffing and untrained junior staff as reported by 43% of hospitals, which resulted in hesitancy in activities related to culture collection of specimens from patients with COVID-19. Nearly 65% of hospitals released formal recommendations or guidance to stop antibiotic use in patients with COVID-19 presenting with no evidence of bacterial infection. More than 50% of hospitals did not update hospital antimicrobial usage guidelines for pneumonia, ventilator-associated pneumonia, or sepsis management. AMSP=antimicrobial stewardship programme. NA=not applicable.

Panel 2: Antimicrobial related challenges in low-income and middle-income countries

- Poor hygiene and sanitation infrastructure
- Tropical climate and high burden of infectious diseases
- Suboptimal investments in laboratory and health-care systems
- Weak regulatory system for the sale of antibiotics
- An absence of skilled workers and human resources for health
- Poor implementation of infection control practices
- Use of antimicrobials in farming and agricultural practices
- Low-risk perception of antimicrobial resistance and its consequences

Panel 3: Antimicrobial resistance surveillance and stewardship gaps

Gaps in human sector surveillance and stewardship efforts reported in the literature include:

- Front-loading in surveillance of antimicrobial resistance and antimicrobial use
- An absence of standardisation in laboratory reporting
- Insufficient access to laboratory supplies including maintenance
- Interrupted supply chains for diagnostics
- An absence of technical training and expertise

In addition to diagnostic and surveillance barriers, stewardship activities in low-income and middle-income countries have the following gaps:

- Over-the-counter sale of antimicrobials hinders appropriate use and monitoring
- Higher levels of falsified and sub-standard antimicrobials
- Weak pharmacovigilance systems
- Communication barriers within programmes preventing understanding of antimicrobial stewardship programme interventions among health-care professionals
- An absence of community engagement

Surveillance System still suffers from poor coverage resulting in concerns about data representativeness and quality.[26] Other initiatives to improve the data quality resulted in the launch of the Fleming Fund by the UK Department of Health, awarding country grants to 22 southeast Asian, south Asian, and African countries to build laboratory and AMU surveillance capacities. The effect of this fund remains to be systematically evaluated. More comprehensive work from a global partnership reported data from 204 countries and revealed the highest AMR burden in sub-Saharan Africa and south Asia.[3] However, this report was also constrained by data disparities with gaps in outcome data and data linkages. Nevertheless, this analysis remains the most comprehensive to date and suggests key intervention strategies for AMR control based on surveillance findings. These intervention strategies included infection prevention and control, vaccinations, reducing inappropriate AMU in humans (driven by an absence of stewardship and infection prevention and control measures) and other sectors, and the development of new antibiotics.

Despite these efforts and complementarities in goals among these initiatives, important gaps still exist in AMR surveillance and stewardship activities that have hindered risk reduction. There is evidence suggesting that the main driver of human AMR is inappropriate AMU,[27] arguably, primarily among humans.[28] Panel 3 highlights deficiencies in AMR surveillance and stewardship systems in the human health sector reported in the literature. Although similar deficiencies exist in the veterinary sector, the sector is highly heterogeneous[29] with several field-specific drivers highlighting the need for participatory approaches to antimicrobial stewardship implementation on a One Health level.

The publication of the global action plan for AMR has seen little in the way of translation of available knowledge and evidence for outcomes for AMR containment globally, especially in LMICs. Irregular progress in attaining AMR goals has been noticed by experts and agencies worldwide. Broadly, three main barriers to progress identified by experts include the absence of contextualised AMR national action plans, reluctance or inability to set meaningful performance targets, and waning momentum in AMR advocacy and leadership.[30] The LMIC action plans developed since 2015 remain unfunded[30,31] with slow progress in implementation of key activities, which has been further hampered by the COVID-19 pandemic. An absence of prioritisation, funding, and accountability were key reasons for slow progress on AMR containment.[1,30–33]

The global context has changed after COVID-19 with policy makers newly cognisant of the importance of scientific evidence, both basic research implications and applied research outcomes. This is an opportunity to capitalise on this altered milieu and rethink the AMR context, review policies, and reset goals and actions.

Leveraging COVID-19 experience to strengthen antimicrobial resistance response

COVID-19 and AMR are both public-health challenges with overlapping issues; however, there are crucial differences. Although both are associated with the concept of One Health requiring a coordinated response at the global level, the complexity of AMR is aggravated because resistance can evolve in several species via multiple mechanisms. Development of new therapeutics and vaccines has been the mainstay of COVID-19 response, but the development of new antimicrobials is not a long-term solution for AMR. Also, the threat perception of AMR among communities and prescribers is vastly different from that of COVID-19.

It is notable that the scientific evidence relevant to AMR in the public space has not catalysed global accountability, warranting governance strategies and corresponding investments. However, policy makers in the post-COVID-19 era are cognisant of the increasing importance of scientific evidence and the necessity of customising interventions to create more responsive systems. The key elements where change was introduced into health systems during COVID-19 are essentially the bottlenecks, which have impeded AMR containment efforts. We therefore believe that the transformations brought about by the COVID-19 pandemic can be utilised for improving governance approaches and increasing accountability, thus positively affecting AMR surveillance and stewardship efforts (figure 2).

Improving governance to strengthen health systems

The successful management of COVID-19 by any country hinged upon effective leadership, efficient coordination, mobilising resource availability, and taking decisive action based on evidence.[34] Many LMICs adopted a top-down and multisectoral governance approach with collaboration between different ministries to ensure effective coordination for COVID-19 response.[35] The scientific advisory groups that included epidemiologists, clinicians, virologists, and infectious disease physicians reported directly to decision-maker groups. Since the caseloads and fatalities were being monitored by media in each country,[36,37] leaders were accountable to the public. Accountability thus had a positive influence on tools and outcomes such as dashboard technology for real-time monitoring, data availability, actionability of target indicators, and political responsiveness in HICs[38] and LMICs such as India and Viet Nam.[35]

We propose formulating a multistakeholder national committee on AMR reporting to the highest office of the country with representatives from government agencies, professional organisations, and civil society organisations, and from the private sector and academia to steer and lead national-level AMR containment efforts. Escalating the challenge of AMR to high-level visibility and establishing a national governance mechanism is the first most important step in securing political will, requisite funding, and policy coherence (figure 2). This high-level committee should be entrusted with the task of raising necessary funds for implementation of national action plans (NAPs), while measuring progress by use of well defined indicators enabled by digital platforms developed de novo or utilising ones created during COVID-19 so that monitoring and evaluation become an integral part of NAP implementation. Securing adequate funding for NAPs will guarantee availability of necessary resources to undertake surveillance and stewardship activities, which currently suffer from poor resource allocation in LMICs.[33] At this juncture when laboratory capacity in many areas has been expanded during COVID-19, this high-powered committee can ensure that these capacities are channelled towards strengthening AMR surveillance.[30]

Data fragmentation is one of the key challenges faced by LMICs that restricts comprehensive understanding of AMR and antimicrobial use within and across all sectors. By engaging with other ministries, the committee will bring them onboard towards a One Health approach for AMR containment and create mechanisms for data consolidation across all sectors. This committee should also create mechanisms for periodic review of available evidence to guide policy changes and prioritisation of activities. The success of similar governance models has been previously documented in Thailand. A multi-ministerial group for implementation of NAP–AMR, reporting to the prime minister's office, was able to raise visibility of the initiative, consolidate scattered national efforts, and document considerable progress on all goals of NAP–AMR.[39]

AMR containment in LMICs is going to be a long battle that needs to be supported by diagnostics, therapeutics, and vaccines. Reliance on imported products leads to shortages, interrupted supply chains, and so on, thus impeding the momentum of progress.[40,41] By supporting an enabling environment for multisectoral engagement and collaborative research between academia and industry via public–private partnerships within the country, this committee can facilitate the development of affordable diagnostics, therapeutics, and vaccines and work with regulators for their efficient inclusion in health systems. With a global push towards implementing universal health coverage and more countries moving closer to its roll-out, this high-level group will also ensure coordination of a national AMR agenda with universal health coverage roll-out and maintain its sustainability.[42]

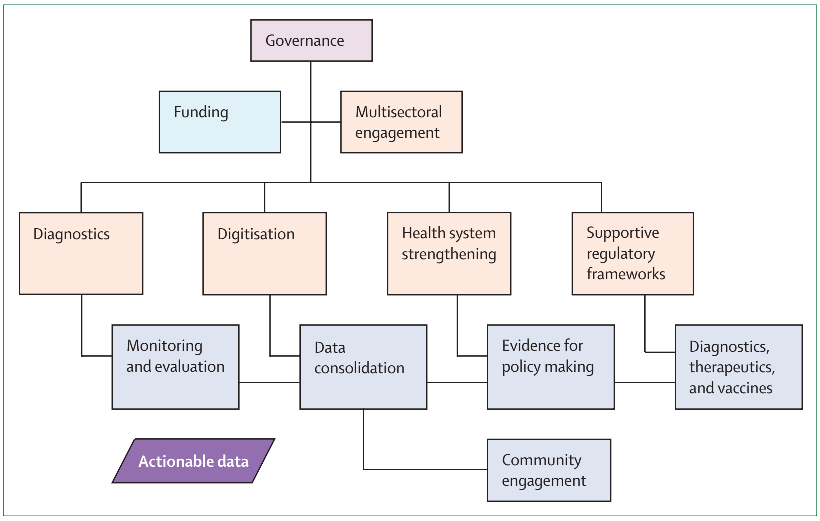

***Figure 2:* Governance model to achieve well funded and sustainable antimicrobial resistance surveillance and stewardship frameworks**
Governance is the most crucial piece of the proposed recommendations. Having a high-level strong governance will ensure availability of sufficient funds to undertake all proposed activities such as laboratory strengthening, creating a digital system for tracking key performance indicators, strengthening of health systems needed for introducing infection control, antimicrobial stewardship practices, and harmonising regulatory standards with international regulations. High-level governance will also be crucial for multisectoral engagement. The data collected will therefore be used for improving implementation, translated into policy making, and used for community engagement and risk communication.

Diagnostic push to improve surveillance and antimicrobial stewardship

The most important lesson drawn from COVID-19 management and control strategies is that the identification of infected individuals and tracing of contacts, regardless of their symptoms, is the most effective mechanism to maintain control of infection and its transmission.[43] The pandemic unleashed a revolution in mass diagnostic testing, which can pave the way for advancing antibiotic-resistant infection detection. Various strategies were used by different countries that augmented COVID-19 testing. Subsidised or free testing models were introduced with investments in building laboratory capacities. Furthermore, the development of robust and rapid, point-of-care molecular diagnostic tests with sensitivity and specificity comparable to the current gold standard assays was instrumental in expanding testing. Advanced molecular testing was used to monitor the pandemic and the emergence of viral variants, and biomarkers to guide management of moderate to severe infections in hospitalised patients.[44–47] India made it mandatory that all laboratories performing COVID-19 testing have accreditation from the government or a government recognised agency.[48] This accreditation resulted in improving the quality of testing further to mandatory test reporting from an accredited laboratory. Similarly, setting benchmarks and accreditation requirements for all laboratories undertaking antimicrobial susceptibility testing both in government and private sectors would considerably improve the testing quality and reporting ecosystem.

The traditional methods addressing antibiotic susceptibility testing are expensive and have a long turnaround time, resulting in the initiation of empirical treatment with broad-spectrum antibiotics while awaiting culture results.[49] Fast and efficient point-of-care diagnostics can be a universal solution crucial to AMR containment in low-resource settings but high costs of rapid or point-of-care diagnostics, even when available, have been a key deterrent to their use in LMICs. Low-cost diagnostics for diseases such as malaria and HIV transformed disease detection in LMICs. Therefore, investing in development of reliable, sensitive, and affordable point-of-care diagnostics like rapid diagnostic tests to identify diseases such as undifferentiated fever and typhoid, could have a tremendous advantage for expanding AMR surveillance and supporting the practice of antimicrobial stewardship in settings where laboratories are not optimally functional.[18] Prevailing high cost of the available point-of-care tests is the biggest barrier to their use. Programmes such as the Access to COVID-19 Tools Accelerator for access to COVID-19 tests in LMICs can be developed on a global level to address the problem of high costs for AMR diagnostics.[18]

Making COVID-19 a notifiable disease made it mandatory for all cases of virologically confirmed disease to be recorded, which enabled tracking. Countries should also consider making all infections caused by specific priority pathogens notifiable. This can be facilitated by information systems developed during COVID-19 and will provide the opportunity for an escalated response.

Harnessing the power of technology

Exponential growth of digital solutions and their accelerated adoption was central to COVID-19 pandemic management. Tracking and monitoring surveillance data from application-based platforms was a crucial step forward. India, China, and many other countries successfully launched and used mobile applications for contact tracing via Bluetooth.[50] The availability of positivity rates in every country or city during lockdowns enabled the detection of hotspots, which could be cordoned off to prevent further transmission. Digital data helped with forecasting by refining epidemiological models to project COVID-19 infections and the need for medical interventions. Likewise, creating dashboards for monitoring key performance indicators would be useful for AMR tracking.

The COVID-19 pandemic also opened new vistas for online learning. Since this was a novel virus with many unknowns, the medical community continuously provided emerging understanding and data on the prevention and management of the virus with various online learning tools. There is an opportunity to add AMR-related courses to online learning platforms that were developed during the pandemic. Training on AMR, infection control, and antimicrobial stewardship can be made widely available and mandatory as part of continuing education. Digital platforms can also support wider dissemination of antimicrobial use guidelines, thus encouraging their rational and responsible use.

Digital health care witnessed phenomenal success during the pandemic. Due to the enforced protocols on reduced social interaction, telemedicine became an indispensable tool. Patients were able to consult doctors and other health-care professionals in real time, enabling prompt access to care while restricting crowding. Digital health care also made last mile delivery of health-care services possible in LMICs whereby specialised health-care infrastructure is reduced in remote areas. Since the absence of trained workforce such as infectious diseases physicians and pharmacists was one of the key challenges in optimising antimicrobial stewardship in hospitals in LMICs, it is now possible to share infectious disease expertise across hospitals via telemedicine and the use of virtual platforms, which can be especially beneficial for suburban and rural hospitals. The Infectious Diseases Society of America supports the appropriate use of telehealth for promoting antimicrobial stewardship and to expand its access to community hospitals.[51,52]

Risk communication: a compass to navigate health emergencies

Communicating risks to stakeholders in a public health crisis witnessed a paradigm shift during the COVID-19 pandemic. It was recognised early during the pandemic that communicating risks promptly, effectively, and unambiguously will enhance the ability of stakeholders—policy makers, administrators, health workers, civil society organisations, media, and the public—to act upon and strengthen response and control measures. Across countries, an interesting mix of media combining traditional and new media tools such as print, television, radio, digital platforms such as social media, door-to-door visits, multilingual hotlines, SMS, and voice messages were used to disseminate the latest information about the disease, particularly where community participation was of high importance. Tools such as social media sentiment analysis helped to gauge public response to COVID-19 messaging, to make adaptive improvements, and to neutralise misinformation.

Conversely, the threat of AMR is not as well understood as COVID-19. Indeed, risk communication is one of AMR's weakest links. This fact is recognised in the global action plan on AMR, which aims to improve awareness and understanding of AMR with effective communication, education, and training.[53] COVID-19 gives cause for optimism, as our experiences of the pandemic will help to define solutions centred on an integrated whole-of-government and society approach for AMR. The consistent message-centred approach applied in COVID-19 response should be considered when addressing the AMR challenge. Although consistency in messaging is important, repetitiveness and overexposure should be avoided to lessen public fatigue towards health risk messaging.[54,55]

Adopting a social and behavioural approach to risk communications could provide effective solutions for AMR. Factors influencing the behaviour of patients and prescribers are likely to be context specific and the specific behaviour interventions that bring about lasting change are not well understood.[56] Research studies across countries have found that antimicrobial prescribing culture is being driven by immediate benefits[57–59] and pressures[57,60] while ignoring long-term risks. The absence of government regulation, economic incentives, and pressure to meet patients' expectations have been major determinants influencing antimicrobial prescriptions in communities.[58,61] Patient-related factors such as self-medication and socioeconomic level also influence antimicrobial procurement habits.[62,63] Inappropriate antimicrobial use by communities in under-resourced areas is linked to a lack of knowledge, poor access to health facilities, and a tendency to self-medicate.[58,64] These findings suggest that communication strategies should incorporate insights on the basis of deeper understanding of cultural and societal factors influencing the use of antimicrobials in a particular setting.

Vaccination and antimicrobial resistance

Regulatory flexibility was used by countries to make vaccines rapidly available to their populations. Vaccination is the most underutilised intervention for AMR containment. Cough, cold, fever, diarrhoea, and urinary tract infections are the most common syndromes for which antibiotics are prescribed in the community setting.[65] Upper respiratory tract infections account for 50–70% of antibiotic prescriptions in India and other LMICs.[66,67] There are many vaccines that have the potential to reduce recurrent viral and bacterial infections thus reducing the need for frequent antibiotic prescriptions, yet their uptake is underwhelming as adult immunisation programmes have not been prioritised in LMICs.[68] COVID-19 saw one of the most successful adult vaccination programmes in modern history. Countries should seriously consider expanding the scope of the current COVID-19 immunisation programmes to include influenza, pneumococcus, typhoid, and *Haemophilus influenzae* type B vaccines.[69] Evidence generation documenting the economic effect of vaccination on AMR and long-term effects on morbidity and mortality can be particularly helpful in facilitating this decision. LMICs should also prioritise research on the development of new vaccines that would contribute to the prevention and control of AMR.

Conclusion

AMR and COVID-19 have a complex relationship at various levels of health care. The pandemic exposed weaknesses in AMR surveillance, diagnostic and antimicrobial stewardship, and infection prevention efforts that predated COVID-19 and negatively affected the AMR response. However, the pandemic resulted in some successes that can be used to strengthen the AMR response in a post-pandemic world.

First, leadership with accountability during the pandemic was exceptional and was instrumental in creating an environment of collective responsibility between government and community. Strong commitment within governments translated into timely allocation of funds from within country budgets, fixing responsibility, and accountability. All these governance practices are absent in the AMR landscape. NAPs were envisaged to provide the necessary impetus for AMR containment efforts within countries. Yet, by not prioritising the AMR crisis and unlike COVID-19, NAPs in most countries are not backed up with an operational plan and domestic financing, thus making them inconsequential to AMR surveillance or stewardship improvement.

Second, it will be a lost opportunity if the frameworks for diagnostic development, testing, and vaccine delivery created during the pandemic are not leveraged to augment AMR containment efforts. Many LMICs struggled to harness these opportunities due to financial, infrastructural, and human resource challenges, yet the in-country development of such resources will result in overall health system strengthening, thus auguring for intensifying AMR surveillance and stewardship strengthening efforts.

Third, advances in real-time surveillance and its translation into constantly updated COVID-19 dashboards and digital platforms was a key feature of COVID-19 management that helped tailor response teams and strategies for pandemic control. Country-specific and context-specific leadership can capitalise on the available information to shape evidence-based policies for AMR, facilitated by direct investment in both diagnostics and digitisation. In addition to improving the surveillance and response capabilities, digitisation will support monitoring of key performance indicators, use digital solutions for stewardship activities, purposively use data dashboards and diagnostics for triage and population management, and repurpose the health-care workforce to reach stewardship targets.

Lastly, to drive sustainable change in use of and access to antimicrobials, it is important to create an enabling environment that addresses the inadequacies of the health system and is supported by integrated communication approaches and community engagement.

COVID-19 also saw disintegration of global solidarity and the undermining of efforts to facilitate equitable access to health counter measures. There were breakdowns of coordination and collaboration that affected access to vaccines, personal protective equipment, and oxygen driving LMICs onto a path of self-reliance. Learning from these shortcomings, efforts should be made to build a cohesive and enforceable response at a global level, while considering local context when deciding on national commitments.

In every crisis lies an opportunity and COVID-19 is one such opportunity to rewrite the narrative on tackling AMR. It is imperative that we have a strong and committed leadership, public engagement, sharing of evolving knowledge, sustainable policies, and a customised approach that is flexible to help to surmount all obstacles. The lessons learnt can be a game changer in our fight against AMR.

Contributors

All authors contributed to the conceptualisation of the review. KW, RS, and SV conceptualised the manuscript, figures, and tables. MM, GK, RV, RS, BV, BB, CR, NB, PR, PM, RG, and VCO contributed to drafting the manuscript. MM, GK, and RV contributed to the section on the management of COVID-19. RV, RS, BV, BB, CR, NB, PR, PM, RG, and VCO contributed to the sections on addressing challenges in AMR and shaping the recommendations. All authors read and approved the final version of the manuscript.

Declaration of interests

We declare no competing interests.

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