Knocking Out AMR Workshops | Summary Report

1. Background

Antimicrobial resistance (AMR) is an urgent and devastating threat to healthcare systems and economies across the globe and is now a leading cause of death worldwide, killing more people than HIV and malaria combined [1]. Solutions to the AMR crisis are desperately needed and microbiologists are at the forefront of developing innovative approaches to minimising the devastating effects of AMR.

In recognition of this, the Microbiology Society has launched the 'Knocking Out AMR' project, an ambitious, bold and extensive scheme of work aiming to promote feasible and effective solutions to AMR over the next five years. Through this project, the Society aims to act as a conduit for cross-disciplinary and multi-sector collaboration against AMR and to support a mandate for urgent policy action. Knocking Out AMR is focusing on three broad priority solution areas/themes: therapeutics and vaccines, diagnostics and surveillance, and policy engagement.

To kickstart the project, the Society hosted a series of solution-oriented, invite-only workshops to improve our understanding of how current systems prevent the development and implementation of solutions to AMR, and how those systems interact are transdisciplinary, acting across research fields, disciplines and sectors.

1.1 Knocking Out AMR Workshop Series

Experts in the field were invited to a series of eight workshops throughout January 2024, with two workshops dedicated to each of the following priority solution areas: diagnostics, surveillance, therapeutics and vaccines. The workshop series was chaired by Dr Tina Joshi, University of Plymouth and Dr Catrin Moore, City St George's, University of London.

The workshops were attended by 135 expert stakeholders (see Appendix 1) from a range of sectors including academia, industry, clinical and veterinary settings, regulatory bodies, funding bodies, national and international policy agencies, not-for-profit organisations and knowledge exchange networks. The expertise of attendees also covered the three 'One Health' settings (humans, animals and the environment) and a wide range of microorganisms (bacteria, fungi, viruses and parasites).

1.2 Workshop structure

Each half-day workshop involved two breakout sessions in smaller groups, followed by a third session in which the groups reported back on their breakout session and the floor was opened up for further discussion.

In the first breakout session, attendees were asked to explore their solution area using a 'complex systems mapping' approach [2]. Participants were asked to discuss:

1. Their vision of a world in which diagnostics, surveillance, therapeutics or vaccines were being used effectively to combat AMR.
2. Interventions that are necessary in order to make this vision a reality.
3. Barriers that prevent implementation of these interventions.

4. Interactions between all of the visions, interventions and barriers that were discussed in the session.

The second breakout session involved a deeper dive into the participants' specific areas of expertise. This session also included a discussion of the roles that learned societies and policymakers can play in removing barriers faced by the AMR community and implement key interventions.

2. Workshop series overview

While the outcomes of the workshops were not exhaustive, they highlighted some of the key issues the AMR community faces and identified critical interventions necessary to drive forward the solutions to AMR. The systems mapping approach revealed the profound complexity involved in addressing AMR and highlighted how interconnected and multifaceted the AMR landscape is, involving multiple sectors and disciplines, each facing common barriers.

These barriers can be broadly categorised into three distinct challenges:

- **A failure to grasp the urgency of the AMR crisis.** Political leaders worldwide fail to grasp the urgency and scale of the crisis. Despite strong evidence of their potential to reduce the burden of AMR, innovative diagnostics tests and surveillance systems together with preventative tools, including vaccines, fail to be embedded in our health systems [3].
- **A broken innovation pipeline.** The current innovation pipeline is hindered by high upfront costs of research and clinical trials, and a lack of understanding of the potential value of diagnostics tools [4]. Challenges are compounded by current regulatory frameworks, which are not fit-for-purpose and impede innovation [5]. Consequently, this broken pipeline has led to a shortage of AMR experts across sectors, as disillusioned researchers exit the field, exacerbating the challenge of tackling AMR effectively [6].

- **A fragmented AMR landscape.** The complexity of the AMR challenge calls for a cohesive strategy that supports strong coordinated action. However, the current landscape is fragmented, with academics, industry, healthcare professionals, regulators and policymakers operating in siloes. This disconnect is fuelled by a lack of enabling environments, including a lack of responsibility and accountability at both national and international levels, inadequate financing and insufficient cohesion of data collection, storage and sharing. **Without clear leadership, curbing this urgent and potentially catastrophic threat will prove impossible.**

Emerging themes for opportunities across the workshops included: 1) enhancing outward-facing communication to underscore the urgency of addressing AMR and 2) galvanising essential funding and political support by making an economic case for AMR. Just as the 1.5°C climate threshold provides a clear and compelling narrative for climate change; workshop participants highlighted the need to develop a similarly simple and effective talking point to communicate the urgency of the AMR crisis. Discussions also centred around refining economic models to expedite the development of new diagnostics and therapeutics, and advocating for investment in healthcare infrastructure and workforce capacity. Additionally, participants emphasised the importance of comprehensive data-sharing strategies to bolster global AMR surveillance and research efforts.

The insights from the workshop series helped to inform the Microbiology Society's programme of work to deliver the Knocking Out AMR project. A key takeaway from the workshops is the need to

break down the siloed working systems within AMR, enabling truly collaborative, multi-disciplinary working and knowledge sharing. Through delivery of the Knocking Out AMR project, the Society will support this cross-disciplinary working and promote policy discourse to address the challenges facing the AMR community, who are working to drive forward solutions to AMR. You can find out more about the project's activities in the Knocking Out AMR vision statement here.

3. Workshop overviews by solution area

A report was written for each workshop by attending members of the Knocking Out AMR Oversight Group and the Microbiology Society's Impact and Influence Committee. These individual reports have been combined here to give an overview for each of the four priority areas. A complex systems map for each priority area is also provided (see Appendix 2). It should be noted that this summary report is not exhaustive.

The Microbiology Society would like to thank Dr Catrin Moore and Dr Tina Joshi for chairing the workshop series and to the early career co-hosts who helped to facilitate the workshops. We sincerely appreciate the time and valuable expert insights provided by workshop attendees. We would also like to thank the report writers who concisely captured workshop outputs, all of whom are named below.

4. Diagnostics workshops report

Workshop dates: 11 and 12 January 2024
Total number of attendees: 26
Report writer: *Dr Jody Winter (Nottingham Trent University, UK)*

4.1 In an 'ideal world,' what does it look like to use diagnostics effectively as a solution to AMR?

As a starting point for the discussion, workshop participants were asked to envision a world where diagnostics are used effectively as a solution to AMR. They identified the following intended outcomes:

- Every antimicrobial prescription is specific to the microorganism causing infection which is validated by an easy-to-interpret diagnostic test.
- Diagnostics improve patient outcomes and reduce the burden on healthcare systems by guiding timely and accurate treatments, help prevent the spread of infections and reduce unnecessary antimicrobial use.
- Universal access to cheap, fast and precise diagnostics driven by real-world need across One Health settings to promptly deliver useful data and actionable information that will help reduce the selection and spread of AMR.
- Well-designed diagnostics, taking into consideration the whole life cycle of the product- including sustainability, waste disposal and laboratory capacity requirements.

4.2 Challenges and opportunities in using diagnostics effectively as a solution to AMR

Workshop participants explored the challenges and opportunities in using diagnostics effectively as a solution to AMR. They identified the necessary interventions for achieving an 'ideal world' scenario and the barriers to implementing these interventions. The discussion covered the following points:

4.2.1 Diagnostic test development

- Fungi are often neglected in diagnostics and the broader AMR landscape. Diagnostic tools should encompass the full breadth of microorganisms, including fungi, parasites and viruses.
- Current widely used diagnostic microbiology methods are incredibly slow. There is a need for the development of faster diagnostics and more choice in simple, rapid diagnostics.
- The current funding model for diagnostics favours new technologies, potentially neglecting funding needs of existing diagnostic technologies.
- There is a lack of 'pull' mechanisms, incentives for use of current as well as new diagnostic technologies.
- Feasibility must be considered at every stage, including patient-centred considerations (such as the patient's experience and acceptance), alongside laboratory, logistical and clinical training requirements.
- Innovative scientists should collaborate with end users, including those in low-resource settings, to ensure that each new test will perform well in the real world.

- A comprehensive biobank would be an instrumental resource in supporting new diagnostic test development and standardised evidence generation, but its establishment and maintenance would require substantial, sustainable investment.
- To bring new diagnostics through to clinical use, existing clinical research networks should be built on (like those used in the RECOVERY trial for COVID-19 treatments) in order to pool resources as well as work more efficiently and collaboratively on clinical trials focussing on diagnostic tests.
- To support clinical decision-making in the future, the use of machine learning and artificial intelligence (AI) tools should be investigated.

4.2.2 Healthcare infrastructure

- New diagnostic tests must integrate into the existing healthcare system and the community. There is a need to facilitate a pipeline in which researchers and developers can fill gaps for specific needs in patient pathways.
- Companies developing diagnostic tests face challenges with budget and logistics when conducting randomised controlled trials and the validation required for clinical use.
- In the UK, even after licensing, there are barriers to introducing a new diagnostic test into NHS procurement and gaining clinician adoption. For example, there is a requirement to prove test efficacy each time the test is introduced, which leads to slow and fragmented adoption. There is a need for national pathways, supported by sufficient funding, to enable wider adoption.
- NHS laboratories often lack funding, workforce capacity and time for innovation because the focus is on service delivery. Additional funding for research and development teams within NHS laboratories is needed to support forward-looking, transformational work.
- Viewing diagnostics as a service rather than a product could help to ensure continuous improvement, patient-centred care, integration with other healthcare services, adaptability, operational efficiency, and a focus on outcomes and accountability.

4.2.3 Siloed working

- Better collaboration and communication across and between academic researchers and different sectors would lead to more useful biomarkers which could be incorporated into marketable tests for clinical use. Further collaboration across One Health sectors is essential to share insights, practices, and resources. Using diagnostics effectively as a solution to minimise AMR requires trans disciplinarity and stakeholders must engage in outcome-driven activities.
- Academic researchers need to work closely with clinicians to ensure their perspectives on what is needed from new diagnostic tools are considered, improving design and overcoming barriers. Ideally, engaging in collaboration and communication across One Health sectors would facilitate the development of national processes and pipelines for the efficient development, testing and delivery of new diagnostic tests.

- Enhanced communication between the veterinary and human clinical sectors would be beneficial: for example, there are potential learnings, direct translations of diagnostic use from the veterinary sector to human clinical settings and *vice versa*.
- Test developers need to work with governments and NGOs to ensure that the logistical requirements (e.g. cold chain requirement, equipment, water, electricity, network and consumables) necessary for new diagnostics do not prevent their implementation in low-resource and field settings.
- There is potential to create a virtual network across research organisations, diagnostic developers, funders and policymakers to engage around the latest developments in diagnostics.
- A consortium could be created to combine resources for setting up clinical trials and clinical studies for diagnostics designed with AMR outcomes. The Antibiotic Resistance Leadership Group (ARLG), based in the US, was highlighted as a successful model of such a consortium.

4.2.4 Data

- Identification of the pathogen and determination of its susceptibility to an antimicrobial is crucial for antimicrobial stewardship, but not always possible. Where it is possible, it is not always performed.
- AMR is not currently reported as a cause of death in hospitals. Instead, AMR-related deaths are recorded based on the type of infection the patient was described as having, resulting in no specific record of AMR-related deaths.
- Routine and timely updates, along with careful curation of AMR gene databases, are critical to ensure that genotype-based predictions of AMR phenotypic resistance are as reliable as possible.

4.2.5 Communication and education

- Increased public awareness could improve diagnostic development by attracting funding and generating political support.
- The AMR community has not effectively communicated the importance and benefits of diagnostics to policymakers. However, the recent emphasis on diagnostic testing in the COVID-19 pandemic presents a unique opportunity to advocate for the health, economic and societal value of diagnostics in the context of AMR, as the public have become familiar with the use of rapid diagnostic tests.

4.2.6 Training

- Behavioural change within the healthcare system is needed to introduce and then implement widespread use of diagnostic tools. To achieve this, when approved tests with the required sensitivity, specificity and speed become available, specific training should be designed to give clinicians, including GPs and pharmacists, the confidence to test and treat based on the results.

4.2.7 Economics

- Cost is a barrier to reducing timescales for implementing diagnostics across many areas. Antimicrobials alone are often cheaper than diagnostic testing together with antimicrobials,

leading to a lack of impetus to develop and implement innovative technologies. Stronger incentives are needed from governments and policymakers to use diagnostic tools. For example, in the UK, the National Institute for Health and Care Excellence could evaluate the diagnostic AMR pathways and integrate an 'AMR value', where test data means an antibiotic is not incorrectly prescribed.

- Cost-effectiveness should be one of the key performance criteria (along with other parameters such as sensitivity, specificity and accuracy) to evaluate diagnostics.
- To convince policymakers of the benefit of diagnostic tools, the AMR community must emphasise the broader benefits of test results, such as correct treatment, reduced length of hospital stay which reduces the possibility of succumbing to hospital acquired infections, faster patient recovery and return to work, and the potential future costs of AMR due to inappropriate treatments.
- Some publicly traded diagnostic companies are financially unstable and are at risk of being delisted due to high development costs, regulatory challenges and market competition.
- Funding support for new businesses is often too low. Diagnostics test development through the whole life cycle is expensive, which could be addressed through private and public support.

5. Surveillance workshops report

Workshop dates: 11 and 12 January 2024
Total number of attendees: 34

Report writer: *Joseph Elikem Efui Acolatse (Cape Coast Teaching Hospital, Ghana)*

5.1 In an 'ideal world,' what does it look like to use surveillance effectively as a solution to AMR?

As a starting point for the discussion, workshop participants were asked to envision a world where surveillance is used effectively as a solution to AMR. They identified the following intended outcomes:

- Comparable datasets at local, national and international levels to produce accessible, live surveillance data of antimicrobial sales, usage and resistance.
- Adaptable and high-capacity surveillance systems which allow for rapid identification of emerging threats.
- Proactive surveillance across One Health settings to observe long-term trends and assess the success of interventions aiming to minimise AMR.
- Surveillance data that generates an understanding of the key drivers of resistance emergence and transmission.

5.2 Challenges and opportunities in using surveillance effectively as a solution to AMR

Workshop participants explored the challenges and opportunities in using surveillance effectively as a solution to AMR. They identified the necessary interventions for achieving an 'ideal world' scenario and the barriers to implementing these interventions. The discussion covered the following points:

5.2.1 Generating high-quality data for intervention

- Current challenges to generating high-quality data include the complexity of establishing robust governance of data and finding and using data that has already been collected.
- Better sharing of information, especially linked surveillance data, will help to inform prescribing decisions at the local level as well as support higher-level priority setting by policymakers and funders.
- Translating surveillance data into actionable steps to address AMR will require generating real-time, longitudinal data through both passive and active surveillance systems. In addition, data must be interpretable, of sufficient quality, harmonised and applicable across local, national and international levels. To achieve this, the data must have sufficient granularity, which involves utilising high-resolution genomics, phenotypic resistance and the understanding of resistomes. This detailed information is essential to accurately assess the magnitude of the AMR problem and devise new interventions.
- A high number of surveillance samples are collected passively. They originate from clinical settings and are used for diagnosing and treating patients. Robust data cleaning and interpretation are needed to bridge the gap between the collected data and its end users.

Without this translation, the data may not be translated into practical and effective applications, which span across the One Health spectrum and therefore an array of end users who may not be in clinical settings.

- To develop clinical interventions in human health, surveillance should be patient-centric to ensure proper care and treatment at local, national and international levels. Surveillance methods should include appropriate sampling techniques, using robust epidemiological methodology, and consider factors such as attitudes and interests that impact these methods. Diagnostics (e.g., point-of-care testing) should be used to connect clinical testing with surveillance systems.
- Data that should be included in surveillance systems:
    - Census and point prevalence data to understand how changes over time.
    - Drivers and origins of resistance and the interactions across human, animal and health sectors. These could help to build early warning system capacity and guide appropriate interventions, while also serving as a mechanism for the evaluation of these interventions.
    - Linked antibiotic use data, especially in community settings and LMICs.
- Modern tools, such as AI, should be incorporated into existing surveillance systems to augment methods of data interpretation or analysis. This could help to establish a clearer understanding of the influences of AMR residues in the environment and the transmission dynamics amongst humans, animals and the environment.

5.2.2 Integrating surveillance systems

- Developing a holistic, adaptable, harmonised and integrated surveillance system that links data at local, national and international levels is a complex task. In the UK, for instance, AMR data is collected from various sources, including hospitals, local health authorities and national surveillance programmes across the four devolved nations. However, this data is not consistently shared at a national level, hindering comprehensive analysis and coordinated response efforts.
- There is insufficient integration of social science and behaviour change strategies into surveillance efforts, as well as inadequate consideration of cultural contexts and perceptions. Public support alone may not be enough to alter behaviours and implement changes recommended by surveillance efforts.
- Accountability for interpreting and communicating surveillance results needs ownership at a national level, although this is challenging, especially considering that misinterpretation could diminish trust in those responsible.
- National-level systemic deficiencies, such as weak supply chains in many countries globally, impact surveillance efficiency.
- Surveillance data could be routinely collected and shared at a higher level, for example, by the UK Health Security Agency.

5.2.3 Data sharing and collaboration

- Surveillance alone has limitations in determining the overall AMR burden as not all data is shared and the data that is shared may be biased.
- Differences in priorities for surveillance systems exist between HICs (high-income countries (HICs) and LMICs.
- There is a need for increased collaboration among industry, academia and relevant stakeholders to share knowledge and determine priorities around AMR and targets to measure intervention effectiveness. This demands global data sharing across different surveillance systems and collaboration across the One Health spectrum.
- Developing well-established national standards and stratified benchmarking would promote effective public reporting of data, thereby improving data collection and sharing for more meaningful outputs.
- Data should ideally be comparable among countries with different contexts including LMICs. Standardising methodologies or protocols and developing standard surveillance reporting criteria could play a pivotal role in harmonising data collection and reporting approaches to achieve this level of comparability. Such standardisation can integrate AMR surveillance systems into health systems, leveraging existing frameworks such as those for HIV, malaria, and tuberculosis in LMICs, thereby reducing siloed efforts.
- Equitable partnerships are needed to build trust among partners, especially with data ownership and the benefits of research outcomes between collaborators in HICs and LMICs. Building a culture of trust is vital for fostering larger collaborations, while respecting the social contexts of different regions and countries to enhance the sampling, collection and comparison of surveillance data.

5.2.4 Communication and education

- The current definition of 'AMR surveillance' is complex and needs fine-tuning to communicate its purpose and importance to all stakeholders. A proposed definition should convey the importance of surveillance data in minimising AMR while also outlining the limits of what surveillance alone can achieve. If the purpose and framing is clear, this will help to ensure data collection across involved sectors is usable at both patient and local levels, for either therapeutic purposes or to drive policy action nationally. In order to achieve this, an agreement must be reached regarding the goals shared across One Health sectors.
- Simple and concise narratives that demonstrate the urgency of the AMR crisis should be developed for the public and non-scientific audiences. Such narratives could be tied into other key healthcare areas where AMR could have catastrophic effects and result in higher mortality rates (e.g., surgical procedures and chemotherapy). Highlighting the link to infection, resistance and death could also help drive home the importance of AMR surveillance to these key audiences.
- There is potential for a paradigm shift when talking about AMR surveillance, from the economic impact to health welfare and the wellbeing of a nation.

5.2.5 Policy

- Strong political will, national legislation and international commitments to enshrine surveillance priorities would cushion against shocks from changing government priorities.
- Strong incentives for sharing data in both clinical and industrial settings would foster collaborations at national levels.

5.2.6 Funding

- There are significant costs involved in developing and maintaining active, real-time surveillance systems in settings where it is lacking, in part due to a lack of microbiology capacity. There is a need for adequate and sustainable funding for long-term surveillance efforts to devise appropriate interventions together with sufficient buy-in from policymakers to guarantee adequate funding.
- LMICs are dependent on official development assistance, which may not be sustainable.
- Investment in surveillance infrastructure is essential, including investment in laboratories, training for local staff and building capacity to prevent attrition. Investment in surveillance infrastructure is particularly important in LMICs, both in settings where surveillance is already established as well as in those where it is unavailable.

6. Therapeutics workshops report

Workshop dates: 19 and 26 January 2024
Total number of attendees: 34

Report writers: *Dr David Clarke (University College Cork, Ireland) and Professor Chloe James (University of Salford, UK)*

6.1 In an 'ideal world,' what does it look like to use therapeutics effectively as a solution to AMR?

As a starting point for the discussion, workshop participants were asked to envision a world where therapeutics are used effectively as a solution to AMR. They identified the following intended outcomes:

- Highly selective treatment prescription: right drug, right dose, right time.
- Optimised use of antimicrobials.
- No treatment failure due to AMR.
- A functioning economic market for therapeutics.
- Ultimately reaching a point where antimicrobials are not needed.

6.2 Challenges and opportunities in using therapeutics effectively as a solution to AMR

Workshop participants explored the challenges and opportunities in using therapeutics effectively as a solution to AMR. They identified the necessary interventions for achieving an 'ideal world' scenario and the barriers to implementing these interventions. The discussion covered the following points:

6.2.1 One Health, collaboration and siloed working

- The problem of AMR is not restricted to humans and the importance of a One Health approach was reaffirmed. In terms of One Health, the animal and ecosystem dimensions are currently underserved.
- AMR research focuses on bacteria, often neglecting other infections (e.g. fungal, viral and parasitic), which must be addressed. It is important to recognise that resistance to anti-viral, anti-fungal and anti-parasitic drugs are different problems, requiring different solutions. As a result, solutions to AMR require an interdisciplinary and multi-organisational approach, which is dependent on close collaboration between industry, academia and end users.
- All stakeholders should work on a common agenda. This collaborative approach may risk problems with Intellectual Property (IP) and current business models, in which case alternatives such as the Open-Source Pharma model could be explored.
- Veterinary clinicians and microbiologists, as well as medical clinicians and microbiologists, need to collaborate more, to foster the development of new therapeutic tools.

6.2.2 Scientific research and clinical trials

- There are a dwindling number of clinical trials testing combinations of antimicrobials and novel therapeutics. Furthermore, the trials that do proceed are typically small and yield

limited information about the particular pathogen and microbiome response to the treatment and prophylaxis.

- Immunocompromised people and those with co-morbidities, who need to take additional drug combinations, are usually excluded from trial cohorts, but these are the people most affected by AMR. As a result, there is little information about the action of the antimicrobial treatments and drug-drug interactions in the patients that rely on them most.
- Due to the risk-averse nature of regulators and current regulatory barriers worldwide, it is difficult to run certain trials (e.g., effective phage therapy trials, as they are highly specific and different combinations may be needed for each individual taking part).
- There is a disconnect between researchers and whether their research translates to industry or answers a global need. Effective research requires target product profiles to ensure that whatever is being developed fits the urgent need of clinicians and patients.
- Antimicrobial testing and development in pre-clinical mouse models (with acute infections) does not reflect the appropriate clinical conditions in human patients. Therefore, in order to prevent inappropriate dosing that would accelerate the emergence of resistance, a better understanding of the pharmacokinetics and pharmacodynamics (PK/PD) of antibiotics in human patients is needed.
- Standards and guidelines should be established to help research and clinical trials generate AMR outcomes.
- Closer post-marketing surveillance of newly approved antimicrobials is needed to help track the emergence and spread of AMR.
- The development of more meaningful clinical trials in the UK could be achieved by introducing broad licenses for collections of phages to be assessed in trials, in addition to fostering closer collaborations between academics, trial units, regulators and the NHS on trial design and the data collected**.**

6.2.3 Existing and new therapies

- While existing antibiotics still work, empirical therapy needs to be rethought as the right drug needs to be used on the right patient with the right dose at the right time.
- The World Health Organisation (WHO) priority pathogen list has encouraged academics to pursue a more targeted line of therapy development, which in some instances has become too targeted.
- The development of new antibiotics is not necessarily the only solution. There is a lack of funding for this work and, even if developed, new antibiotics are often not used. In order to reduce the spread of resistance, newly available antibiotics should be used selectively in people who have infectious syndromes with AMR.
- Personalised medicine offers a promising pathway for therapeutic development, although workshop participants expressed concerns about the numerous uncertainties involved.
- As a solution to AMR, prevention is preferred over cure. Vaccines and other preventative strategies (e.g. colonisation resistance) should play a key role for the control of some infectious diseases.

- Bacteriophages have been suggested as a potential 'magic bullet' to fight AMR in the short-term. Workshop attendees were largely supportive of bacteriophage therapy while acknowledging that the method is still in the early stages of the technology cycle. There are many questions around phage therapy (e.g. efficacy, acquisition of resistance and immune responses). Notably, the potential risks associated with phage therapy have not yet been fully examined through appropriate clinical trials. Phage use has so far been restricted to compassionate clinical intervention in cases where antibiotics have failed or are beginning to fail. Widespread application of phage therapy, in humans at least, is far from being realised. In fact, significant funding for fundamental research into phage modes of action and the construction of facilities is needed to produce large enough quantities of (appropriate quality) phage required for clinical trials and/or clinical applications.

6.2.4 Polymicrobial infections, co-morbidities and climate change

- It is increasingly recognised that infections are often polymicrobial, involving complex interactions between several co-infecting microbes, the inhabitant microbiome and the host's immune system. These intricate dynamics significantly complicate the drug development process.
- Infections commonly involve biofilms, which protect microorganisms from antimicrobials and promote further development of resistance. However, standard antimicrobial susceptibility testing methods do not reflect these conditions.
- An ageing population and the growing number of immunocompromised people means that infections are also increasingly compounded by co-morbidities such as cancer and kidney disease.
- Climate change is creating more humid conditions which promote the increased emergence of fungal pathogens that are resistant to antifungal drugs.
- A better fundamental understanding of how these various aforementioned conditions affect antimicrobial action is needed.
- Investment in basic research would help to develop sustainable *in vivo* infection models that better reflect complex infections and bridge the gap between *in vitro* antimicrobial susceptibility testing and clinical trials. This would inform smarter design and follow-up of clinical trials.

6.2.5 Data

- There is a lack of microbiology data and that will be hard to overcome as plants, animals, the environment and humans are complex systems.
- Although the emergence and spread of AMR in some pathogenic microbial species is well researched, the acquisition and sharing of new data is vital for the discovery of solutions to AMR. Data on the different interactions between antibiotics and microbial communities (e.g., the gut microbiome) is particularly important. Such experiments are complex, although they use widely available tools. Ultimately, there is a call for this work to move beyond the observational to facilitate the discovery of new therapies.

- AI algorithms could potentially use available patient metadata and assist clinicians to predict drugs for treatment, although this practice would need to address concerns regarding efficacy and security.
- Effective stakeholder collaboration would require developing new ways of sharing data and other critical resources.
- AMR-related deaths should be recorded as such on death certificates.
- Longitudinal datasets for specific infectious diseases and bacteria are needed in order to develop standards and guidelines to generate AMR-related outcomes in research and clinical trials.

6.2.6 Communication and education

- Public and patient engagement is critical to raise awareness of AMR and the responsible use of antibiotics and to share stories of those who have been affected by AMR.
- More research is needed to understand what influences the societal mindset on antimicrobials.
- Supplying information packs and employing a storytelling approach could help to boost awareness, drive investment and broaden reach.
- Increased open access to information should be an opportunity to change public perceptions about antimicrobial treatment through the use of common language.
- Work shadowing schemes between early career clinicians and researchers would boost meaningful knowledge exchange and awareness.
- Trusted public engagement toolkits on AMR could empower educators, researchers and science communicators as ambassadors to raise awareness across different audiences.
- Simple interventions can be effective (e.g., an initiative that provided GPs with mouse mats outlining good practice for prescribing antibiotics has changed behaviour in Ireland).

6.2.7 Training

- There is a bottleneck in the talent pipeline and a global shortage of specialised clinicians, clinical microbiologists and veterinary microbiologists.

6.2.8 Crisis and conflict

- During times of crisis and conflict, there is often a breakdown in infrastructure and increased barriers to access antimicrobials and trained personnel, which can drive the spread of AMR. Research is needed to define and better understand these effects, drawing lessons from the COVID-19 pandemic, and from health professionals and researchers in resource-poor settings. This deeper understanding of the effects of crises and conflict on healthcare will help develop guidance and policies on how to act in such situations to best protect the efficacy of treatment.
- Solutions could include training in AMR for those that work at the coal face during crises and conflict, such as military personnel and community leaders; development of disaster-response plans; and surveillance at key hotspots and travel hubs.

6.2.9 Economics

- The market and ecosystem for therapeutic development are broken. For example, many SMEs (small and medium-sized enterprises) developing new antibiotics in the USA have gone bankrupt. There is a need to ensure all parties receive a return on their investment, which could be achieved through subscription-style models, such as the Netflix model launched by the NHS in the UK.

6.2.10 Funding

- A significant increase in investment is required if new therapies are to be identified and developed for clinical use in a useful timeframe.
- To ensure the sustainability of funding, there is a need to determine what funders are influenced by and potentially re-educate them on the long-term benefits and impacts of their investments.
- There should be an established funding pathway for all stages of developing new antibiotics.

7. Vaccines workshops report

Workshop dates: 19 and 26 January 2024
Total number of attendees: 31

Report writers: *Prof Joan Geoghegan (University of Birmingham, UK) and Dr Tadhg Ó Cróinín (University College Dublin, Ireland)*

7.1 In an 'ideal world,' what does it look like to use vaccines effectively as a solution to AMR?

As a starting point for the discussion, workshop participants were asked to envision a world where vaccines are used effectively as a solution to AMR. They identified the following intended outcomes:

- Availability of vaccines against resistant pathogens that prevent the burden and spread of AMR infections.
- Viral vaccines are used to prevent inappropriate antibiotic usage for viral infections.
- Vaccines are affordable, accessible and effectively deployed globally.
- Development of vaccines that combat AMR is financially viable.
- All countries have access to vaccine testing and manufacturing infrastructure.
- Vaccines are tested in appropriate models, preferably live models (e.g., animals, human challenge models).
- Vaccines are publicly accepted.
- Vaccines prevent AMR infections in livestock.

7.2 Challenges and opportunities in using vaccines effectively as a solution to AMR

Workshop participants explored the challenges and opportunities in using vaccines effectively as a solution to AMR. They identified the necessary interventions for achieving an 'ideal world' scenario and the barriers to implementing these interventions. The discussion covered the following points:

7.2.1 Vaccination strategy

- As vaccine development is a complex process, there should be a focus on the WHO priority pathogens list.
- Realism was an overarching point in the workshops, in regard to the timescale and money involved in vaccine development. There is a need for political understanding of the vaccine landscape.
- Effective multivalent combined vaccines that can target several AMR pathogens are ideal, but the current model necessitates developing an impractically large number of vaccines, posing logistical and individual challenges. While developing an all-encompassing vaccine remains a significant challenge, the focus should be on enhancing efficacy through validation, improvement and exploring combination vaccine strategies.
- Vaccines specific to bacterial pathogens are important for direct prevention of AMR infections. However, vaccines to many viral pathogens could also have an indirect but vital

role in controlling AMR, by reducing the load viral infections and thereby reducing the inappropriate use of antibiotics, as well as through prevention of secondary bacterial infections caused by AMR organisms. To implement vaccines to combat AMR, it will be crucial to establish a convincing evidence base demonstrating the value to health and the economy.

- There should be a multimodal approach to vaccines, education, antimicrobial stewardship and diagnostics to increase the effectiveness of vaccine use.

7.2.2 One Health

- The veterinary field is underserved in terms of vaccine availability and usage.
- The importance of a One Health approach was reaffirmed, emphasising the need to address both animal and human health for vaccines to be an effective tool against AMR, especially considering that animal immune systems are not well characterised.

7.2.3 Scientific research and clinical trials

- Supporting vaccine research is essential. This could be achieved by creating dedicated funding, enhancing support for cross-disciplinary collaborations or consortia, improving infrastructure and the communication around vaccines.
- Developing a better understanding of what defines protective immunity against pathogens is crucial. This knowledge would inform better pre-clinical models for assessing vaccines efficacy in humans, thereby accelerating vaccine development.
- Other critical areas requiring urgent progress include enhancing current adjuvants and developing new vaccine platforms, advancing understanding of targets and protective antigens linked to specific pathogens, identifying populations that would benefit from targeted vaccination, investigating zoonotic microorganisms with potential economic impacts, and validating and improving existing vaccines while developing novel ones.
- Research is needed to understand how vaccines can help to tackle AMR, as well as the cost. The workshops highlighted the WHO's development of a value attribution framework to estimate the value of vaccines in reducing AMR, which could bring about equity and social justice.

7.2.4 Collaboration

- A systemic approach is required to develop vaccines to combat AMR, which necessitates collaboration across a diverse range of fields and agencies. A consistent analogy which emerged was that of building bridges between experts in different fields, from academia to industry to regulators and policymakers, to ensure a collaborative global approach is taken to develop and employ vaccination strategies to combat AMR.
- The AMR community must engage with policymakers and employ a truly global approach (i.e., considering the distinct challenges that would be faced in different international regions).
- There is a need to engage with regulators, as a global approach will require harmonisation of regulation across different jurisdictions.

- AMR is a global challenge and therefore must be tackled on a global scale. Vaccines should undergo testing and manufacturing in regions bearing the heaviest AMR burden, where their benefits will be most significant. This will require substantial investment in infrastructure. All stakeholders (regulators, policymakers, industry, funders, clinicians and researchers) have a significant role to play. A collaborative approach is key to ensuring that progress can be made.
- There is a need to appreciate population differences. Different pressures exist in LMICs and HICs; consequently, their respective needs and ability to deploy vaccines are markedly different.
- There are inadequate mechanisms for sharing data, samples and strains. As a solution, biobanks containing samples of different strains could be established to provide access to relevant strains and clinical data and thereby facilitate the development of effective vaccines.
- Prioritising a particular vaccine platform or strategy should be avoided. Instead, by building partnerships between different stakeholders and promoting a vaccine-based strategy to combat AMR, a significant impact could be made through multiple complementary approaches.

7.2.5 Data

- The impact of vaccines should be measured to establish how the increased use of vaccines leads to less antimicrobial usage. However, it is uncertain whether the appropriate data to monitor this is even available or achievable. This data and the evidence it provides is needed to fully realise the potential of vaccines as a solution to AMR.
- There is a wealth of high-quality grey literature which is currently not being used, which AI could potentially help process. Grey literature encompasses materials and research produced by organisations outside of the traditional academic or commercial publishing systems.

7.2.6 Communication and education

- Vaccines are crucial in combating AMR, yet effectively communicating this information to the public and various stakeholders remains challenging. Using education and vaccines promotion to address public vaccine hesitancy and to underscore to industry and policymakers that vaccination is a critical tool in combatting the rising tide of AMR are pivotal for success. This requires intensified efforts to highlight the economic and health benefits of vaccines, both for individuals and the broader public health.
- The framing around vaccines must acknowledge that unlike antibiotics, it is less evident to the individual recipient when vaccines work.
- Personal narratives and a storytelling approach could be used to increase public understanding of the benefits of vaccines as a solution to AMR.
- The scope of vaccines, as a definition, should be broadened to include the use of monoclonal antibodies and trained immunity.

7.2.7 Training

- There is a lack of training for academic scientists, particularly concerning regulatory issues around vaccines.

7.2.8 Regulation

- Regulatory protocols are individualised according to industry. Moving forward, regulatory protocols should be unified under one particular voice.

7.2.9 Economics

- Some diseases, despite their impact on public health, lack a sufficient market to justify vaccine development.
- Cost-efficiency is a critical factor for vaccine development, partly because it is industry-driven rather than research-driven. Understanding cost-effectiveness necessitates a deep understanding of the long-term dynamics of vaccine systems.

7.2.10 Funding

- Investors are hesitant to support vaccine development due to the high development costs, the lack of perceived need and the lack of financial incentives to support vaccine development by SMEs and within academia. Balancing return on investment with the need for affordable vaccines remains a challenge.
- There is an urgent need to increase funding for testing vaccines in livestock and advancing veterinary vaccinology.
- Research funders should mandate early engagement with industry and regulators during vaccine development to leverage expert guidance effectively.
- Regulatory protocols are individualised according to industry. Moving forward, regulatory protocols should be unified under one voice.

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Appendix 1. List of attendees

Note that some participants chose to remain anonymous.

Chairs

- Dr Tina Joshi, University of Plymouth
- Dr Catrin Moore, St George's, University of London

Early career co-hosts

- Dr Ainsley Beaton, John Innes Centre
- Dr Eva Benyei, University of Cambridge
- Dr Genet Tadege, Jimma University
- Dr Isobel Garratt, University of Bath
- Dr Natalie Ring, The Roslin Institute
- Dr Omololu Fanguwa, Queen's University Belfast
- Dr Paz AranegaBou, UK Health Security Agency
- Dr Zara Rafaque, Hazara University, Mansehra

Diagnostics	**Surveillance**
Dr Jody Winter, Nottingham Trent University	Joseph Elikem Efui Acolatse, Cape Coast Teaching Hospital
Dan Andersson, Uppsala University	Dr Alicia Demirjian, UK Health Security Agency
Dr Leonid Chindelevitch, Imperial College London	Dr Ed Haynes, Food Standards Agency
Professor Till Bachmann, University of Edinburgh	Dr Jan-Ulrich Kreft, University of Birmingham
Dr Ibrahim Yusuf, Bayero University Kano	Dr Katherine Henderson, UK Health Security Agency
Professor Jodi Lindsay, St George's London	Dr Marlieke de Kraker, Geneva University Hospitals
Professor Kristen Reyher, University of Bristol	Dr Stephan Harbarth, University of Geneva
Dr Neil Stone, Hospital for Tropical Diseases/University College London Hospital	Dr Aisling Glennie, Veterinary Medicines Directorate
Dr Janet Midega, Wellcome Trust	Dr Alwyn Hart, Environment Agency
Dr Lucy Bock, UK Health Security Agency	Dr Colin Brown, UK Health Security Agency
Professor Susan Hopkins, UK Health Security Agency	Dr David Verner-Jeffreys, Centre for Environment, Fisheries and Aquaculture Science (CEFAS)
Dr Denise O'Sullivan, National Measurements Laboratory, LGC	

Dr Magdalena Karlikowska, Cytecom Jean-Louis Tissier, BioMerieux Philippe Leissner, Bioaster Yoann Personne, BioMerieux Professor Pantelis Georgiou, ProtonDX Dr Silvia Bertagnoli, World Health Organisation Pete Dailey, CARB-X Dr Francois- Xavier Babin, Fondation Merieux Helen Dent, BIVDA Dr Robert Leo Skov, International Centre for Antimicrobial Solutions Jayne Ellis, BIVDA Professor Arindam Mitra, Adamas University Dr Rob Shorten, Lancashire Teaching Hospital Dr. Seshasailam Venkateswaran, Queen Mary University London Dr Ghada Zoubiane, International Centre for AMR Solutions	Dr Gwen Knight, London School of Hygiene and Tropical Medicine Dr Julie Robotham, UK Health Security Agency Dr Karen Forrest, London School of Hygiene and Tropical Medicine Dr Nimesh Poudyal, International Vaccine Institute Dr Pascale Ondoa, African Society for Laboratory Medicine Dr Patricia Bradford, Vivli Dr Sergey Eremin, World Health Organisation Professor Ben Cooper, University of Oxford Professor Clare Chandler, London School of Hygiene and Tropical Medicine Professor Finola Leonard, University College Dublin Professor Iruka Okeke, University of Ibadan Professor Kat Holt, London School of Hygiene and Tropical Medicine Professor Matthew Avison, University of Bristol Professor Nicholas Feasey, London School of Hygiene and Tropical Medicine Professor Sarah Walker, University of Oxford Professor Sharon Peacock, University of Cambridge Professor Stephen Baker, University of Cambridge Professor Timothy Walsh, University of Oxford Professor William Gaze, University of Exeter Professor Robin May, Food Standards Agency

	Sabrina Yesmin, Directorate General of Drug Administration, Ministry of Health and Family Welfare, Bangladesh Ute Sonksen, Statens Serum Institute
Therapeutics	**Vaccines**
Dr David Clarke, University College Cork Professor Chloe James, University of Salford Carl Curran, Infex Therapeutics Clive Mason, LifeArc Dr Jonathan Cox, Aston University Dr Mike Allen, MSD Dr Raheelah Ahmad, City University Dr Yingfen Hsia, Queens University Belfast Dr Adam Roberts, Liverpool School of Tropical Medicine Dr Andrew Edwards, Imperial College London Dr Colin Brown, UK Health Security Agency Dr Derry Mercer, Bioaster Dr Douglas Fraser-Pitt, Keele Universiy Dr Esmita Charani, University of Liverpool Dr Francesca Hodges, Innovate UK Knowledge Network Dr Peter Jackson, Infex Therapeutics Dr Rachel Freeman, IQVIA Dr Sean Wasserman, St George's, London Dr Thamarai Schneiders, University of Edinburgh	Joan Geoghegan, University of Birmingham Dr Tadhg Ó Cróinín (University College Dublin Dr Christina Dold, Moderna Dr Andrew Preston, University of Bath, Milner Centre for Evolution Dr Anjam Khan, University of Newcastle Dr Boon Lim, Oxford SimCell Dr Debbie King, Wellcome Trust Dr Ed Buurman, CARB-X Dr Erta Kalanxhi, One Health Trust Dr Gabriela Juarez Martinez, Innovate UK KTN Dr Jeremy Salt, The Vaccine Group Dr Phil Packer , Innovate UK UKRI Dr Siobhán McClean , University College Dublin Dr Stephen Reece, Kymab Sanofi Freddy Kitutu, Makerere University Michael Kowarik, Lmtbio Obadiah Plante, Moderna Prof Stephen Cambell, University of Manchester Professor Adam Cunningham, University of Birmingham

Lloyd Czapleswki, Chemical Biology Ventures Limited Prof Stephen Campbell, University of Manchester Professor Angharad Davies, Swansea University Professor Darius Armstrong-James, Imperial College London Professor Diane Ashiru-Oredope, UK Health Security Agency Professor Fiona Walsh, Maynooth University Professor Janet Hemingway, Infection Innovation Consortium Professor Jean-Yves Maillard, Cardiff University Professor Lindsay Hall, Quadram Institute Professor Mark Holmes, University of Cambridge Professor Martha Clokie, University of Leicester Professor Mat Upton, University of Plymouth Professor Philip Howard, NHS Professor Roberto La Ragione, University of Surrey Richard Alm, CARB-X	Professor Cal McLennan, Bill & Melinda Gates Foundation, The Jenner Institute University of Oxford Professor Christine Rollier, University of Surrey Professor Jeffrey William Almond, The Sir William Dunn School, University of Oxford Professor Jeremy Brown, UCL Professor Mark Stevens, The Roslin Institute Professor Peter Borriello, Safe Medicines for Animals Professor Robert Heyderman, UCL Professor Simon Graham, Pirbright Institute Ronnie Alexander-Passe, GAMRIF Sir Andrew Pollard, Oxford Vaccine Group

Appendix 2. Systems maps

Systems maps guide

For all the following systems maps, pink boxes represent the 'ideal world' scenario/intended outcomes. Orange boxes represent the interventions needed to achieve these outcomes, green boxes represent challenges or barriers that need to be addressed. Individual sub-maps were developed in the breakout rooms on Microsoft Whiteboard by identifying the ideal outcomes, necessary interventions, barriers, and pathways linking them. The guiding star statement (shown in the dark green box) represents the desired system behaviour. For each theme (diagnostics, surveillance, therapeutics and vaccines), the sub-maps (eight in total) were combined into a map shown here by pulling out and combining key themes. Arrows illustrate interactions. Box sizes do not reflect scale or significance, and no prioritisation was attempted.

List of abbreviations for the systems maps

- AI: Artificial intelligence
- AMR: antimicrobial resistance
- AMU: antimicrobial use
- CARE: collective benefit, authority to control, responsibility, ethics
- CRP: c-reactive protein
- DIVA: differentiating infected from vaccinated animals
- FAIR: findable, accessible, interoperable, reusable
- IV: intravenous
- LIMS: laboratory information management systems
- LMICs: low- or middle-income countries
- ML: machine learning
- PKPD: pharmacokinetic/pharmacodynamic
- POC: point-of-care
- RCT: randomised controlled trial
- SMEs: small- and medium-sized enterprises
- WHO: World Health Organization

KNOCKING OUT AMR

Using diagnostics effectively as a solution to AMR

- Implement NICE recommended rapid point of care CRP testing
- Invest in technological improvements
- In vitro-in vivo paradox studies
- Standardize outputs
- Diagnostic outputs vary
- Repurpose COVID-19 diagnostic infrastructure
- Clear protocols embedding diagnostics into current pathways
- Improve awareness and use of existing tools
- Improve clinical and community coding
- Facilitate data sharing
- Regular, broad and ongoing testing
- Need for more accurate and rapid diagnostics
- Communicate test results to patients
- Make terminology accessible
- Extensive public awareness campaigns
- Capitalize on momentum from COVID-19
- Implement testing at pharmacies and community centers
- New technology bias
- Large-scale implementation studies
- Variation in clinical pathways and workforces
- Diagnostics generate live surveillance data
- Rapid and accurate POC diagnostics
- Patients trust diagnostics
- Patient pressure to prescribe
- Regular training for prescribers
- Effective implementation
- Lack of available evidence that pathways utilising diagnostics are cost effective and affordable
- Prescribers have confidence in decision-making
- AI-assisted decision making
- Overloaded health professionals
- Outputs directly inform treatment
- 'Black box' diagnostics
- Universally accessible diagnostics
- Consider access throughout design process
- Process for evaluating in-context effectiveness
- Fit-for-purpose diagnostics
- Antimicrobials are only prescribed when necessary
- Diagnostics for self-limiting infections
- Advocate for the importance of diagnostics
- Feedback loops
- Disconnect between developers and end users
- Diagnostics used across One Health
- Reduced burden of AMR infections
- Funders and policymakers focused on therapeutics
- Health economic analyses
- Improve quality of animal diagnostics
- Animal diagnostics are overlooked
- Diagnostics are valued
- Lack of data showing the impact of diagnostics on AMR
- Diagnostics cover all infections
- One Health spaces siloed
- Non-invasive diagnostics for livestock
- Unified diagnostic pipeline
- Diagnostic development is commercially viable
- Incentives for investing in diagnostics
- Funders and regulators require real world evidence
- Contact opportunities
- Disease fields siloed
- Complex microbial populations
- Fungi and parasites overlooked
- Regulatory inconsistencies
- Academia and industry are siloed
- Clinical trial cost and design
- Procurement issues
- Risk management schemes
- Generate evidence base for diagnostics
- Clear governance
- Increased long-term research funding
- Improve distribution of funding
- Widen microbial focus and expand priority pathogen lists
- Expediate and harmonize regulatory approval
- Increase job mobility between sectors
- Incentives and opportunities for public-private collaboration
- Educate academics on industry and clinical trials
- Combined RCTs for small companies
- High initial development costs
- Improve economic models for diagnostic development
- Engage big pharma, equity companies and venture capitalists
- Invest in biobanks
- Frameworks for assessing diagnostic tests
- Intellectual property
- Research sharing and communication

MICROBIOLOGY SOCIETY

KNOCKING OUT AMR

Using surveillance effectively as a solution to AMR

Longitudinal studies in wastewater, manufacturing and agriculture settings

Health economic analyses

Public engagement campaigns

Invest in training and maintaining workforce

Record clinical context, treatment pathways and patient information

Context-specific feedback systems

Clinical data collectors aren't educated about surveillance

Standardize methodology reporting

Standardize outputs from diagnostic tests

Validate new gold-standard methods

Allocated funding for non-human surveillance

Effective communication with policymakers

Difficult to make cost-benefit argument for surveillance

Clarity around the purpose of surveillance

Collect data at the appropriate time and place

Surveillance data isn't communicated back to health professionals

Standardize sampling frameworks

Variation in data collection and sample preparation methods

Bias towards human-centric and infection-led surveillance

Value and need for surveillance is understood across sectors

Meaningful surveillance outputs improve patient care

Harmonized data collection methods

Well-established data quality standards

Lack of engagement from policymakers

Lack of simple One Health diagnostics to generate data

Collect resistance data for all types of microbe

Passive and active surveillance across One Health

Able to combine and compare datasets at all levels (local, national & international)

Share raw and cleaned data

Incentives for data sharing

Public advocacy for surveillance

Clarification surrounding data ownership

Sustainable funding for surveillance in places with high prescribing

Dedicated frameworks for AMU surveillance

Effective surveillance of AMU

Accessible live surveillance data

National and international data-sharing legislation

FAIR/CARE data principles

Instability of funding programmes in LMICs

AMU difficult to measure due to self-medication

Data communication and visualization systems

National efforts to measure antimicrobial sales

Public-private collaboration

Adaptable, high-capacity systems

Surveillance improves our understanding of AMR

Install pathogen genomics technologies in public health labs

Cost of genomic surveillance

High cost of running surveillance programmes

Use data to mechanisms of emergence and key drivers of transmission

Unwillingness to incorporate new technologies

Incentives for industry to run surveillance projects

Surveillance systems aren't designed to fit into healthcare systems

Able to observe long-term trends

Able to assess the success of interventions

Rapid identification of emerging threats

Able to identify infection origin and risk groups

Record all data (including negative isolates), not just data immediately relevant to patient care

Existing surveillance systems are siloed

Only performing reactionary surveillance

Integrate AMR surveillance into existing healthcare systems

Discontinuous data

Integrate different data types to build a bigger picture

Invest in early warning systems

Increase numbers of sentinel sites

Better utilization of existing data

Parallel sampling of clinical, food and environmental samples

Whole resistome approaches

Commensal flora sampling

Centrally coordinated healthcare systems and surveillance efforts.

Proactive, longitudinal surveillance studies

Improve data analysis and interpretation tools

Long-term government mandates

MICROBIOLOGY SOCIETY

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Using therapeutics effectively as a solution to AMR

- Research comorbidities and immunocompromised patient responses
- Invest in AMR-microbiome research
- Improve social media engagement
- Make economic case in LMICs
- Use personal and relatable narratives
- Develop evidence base for best practice and adapt to context
- PKPD studies and serum drug monitoring
- Lack of pharmacodynamic markers
- Research polymicrobial infections and mixed populations
- Prioritize high-burden infections (e.g. ESKAPE pathogens)
- Require toxicity awareness for all antimicrobials
- Avoid preaching
- Effective public education campaigns
- More realistic model systems
- In vitro – in vivo paradox
- Involve health professionals
- Lack understanding of risk factors for antibiotic failure
- Lack understanding of microbiomes and allergies
- Over-the-counter antibiotics (LMICs)
- Patients pressure overloaded health professionals to prescribe
- Simple guidelines for prescribers
- Improve tissue penetration
- High-quality, efficient therapeutics
- Improve patient outcomes
- No negative side effects
- Lack of IT interconnectivity
- Antimicrobials always formally prescribed, and only when necessary
- Decision making software
- Invest in healthcare workforce
- Focus on direct-acting antimicrobials targeting biofilms and resistors
- Diversify 'first-line' antibiotic use
- Cover full range of microbes across One Health
- Trials to determine optimum dosing and course length
- Site-specific therapeutics e.g. immune/pH-activated
- Highly selective targeting and dosing
- Infection is controlled in animals and the environment
- Host-specific therapeutics
- Shorten half-lives to reduce environmental reservoirs
- Appropriate pack sizes
- Effective infection prevention and control measures (e.g. vaccines)
- Antimicrobials aren't needed
- On-site, need-driven manufacturing
- Manufacturing facilities are outsourced
- Design infrastructure to meet need
- Supply chain instability leads to shortages
- Improve supply chain stability and transparency
- Involve regulators and policymakers early in development
- Regulatory disparities
- Approval process is difficult for alternative therapeutics
- Functional regulatory landscape
- New antimicrobials regularly developed
- Design evolving therapeutics
- Use AI and ML to design new antimicrobials
- Adaptive, pro-innovation regulations
- 'Perfect' data requirements create RCTs that aren't applicable to real patients
- Range of alternative therapeutics protect antimicrobial arsenal
- Accessible and affordable therapeutics
- Functioning financial market
- Industry 'brain drain'
- Invest in training young people with translational skill sets
- 'Valley of death'
- De-risking strategies
- Frameworks for collaborative publishing
- Clear governance structures
- Target over-prescribed infections with alternatives
- Clinical trials for alternative therapeutics
- Funding too focused on applied research
- Alternative therapeutics aren't affordable
- High development costs
- Lack of funding for SMEs
- Profits based on sales volume
- Opportunities for public-private collaboration
- Invest in immunotherapy research
- Funding inclusion criteria limits innovation
- Increased cross-sector funding for alternative therapeutics
- Blue sky research funding for phages
- Accessible delivery systems (e.g. oral over IV)
- Push incentives
- Industry-specific funding pots
- Pull incentives e.g. subscription models
- Improved economic models e.g. open source pharma
- Political will
- Build trust between stakeholders
- Incentives for big pharma to re-enter AMR space
- Make the economic case to other therapeutic industries e.g. oncology
- Educate policymakers and academics on the timescale and process of developing a new antimicrobial
- Health economic analyses

MICROBIOLOGY SOCIETY

KNOCKING OUT AMR

Using vaccines effectively as a solution to AMR

- Vaccine hesitancy
  - Tailored communication for different stakeholders
  - Honesty and transparency about side effects
  - Health economic analyses to show vaccine benefits
  - Involve social and behavioural scientists
  - Reduce risk of adverse effects
  - Public education campaigns and narrative work
  - Identify reasons for vaccine hesitancy in different contexts
- Vaccine fatigue and crowded schedules
  - Aligned vaccine schedules
  - Combination vaccines
- Disinformation
- Vaccines are publicly accepted
- Vaccines cover all types of microbial infection
  - Dominated by WHO priority pathogen list
    - Parasitic and fungal vaccines
    - Research non-ESKAPE pathogens
  - Bacterial vaccines aren't well understood
    - Invest in bacterial vaccine field
- Vaccines are affordable and accessible
  - Expensive storage conditions
  - Needle-free delivery systems
- Vaccines are effective
  - Lack of effective adjuvants
    - Improve criteria for adjuvant success
    - Invest in adjuvant research
  - Improve efficacy of current vaccines
  - Efficacy varies in different populations
  - Difficulty mimicking natural human immune response
    - Lack understanding of protective antigens
      - Connect structural biologists and immunologists
      - Sustained funding for basic immunology research
      - Invest in researching vaccine-host interactions
      - Microbiome research
    - Find more clinically relevant models
      - Mode of action studies
  - Pathogen complexity and multivalency
    - Find antigens present throughout infection
  - Vaccine platforms
- Vaccines are manufactured at scale where the infection is relevant
  - LMICs aren't considered in business models
  - Invest in building manufacturing facilities where infection is relevant
  - Adapt and streamline manufacturing processes
  - Manufacturing is out-sourced
  - Manufacturing bottlenecks (fill-finish)
- Vaccines are a major tool for tackling AMR
  - Lack of awareness of vaccine role in AMR
    - Connect immunologists to AMR community
      - Strong and unified messaging
        - Specific labelling for AMR vaccines
    - Incorporate AMR into vaccine trials and measures of success
- Vaccines reduce AMU
  - Use viral vaccines to prevent unnecessary prescribing and secondary infections
  - Underutilization of viral vaccines
- Effective vaccine deployment programmes
  - Improve distribution chains
    - Make vaccine networks more global
  - Engage with local policymakers
    - Consider target population and deployment context during development
- Vaccines against AMR are financially viable
  - Vaccines against AMR pathogens
  - Identify drivers of AMU in different contexts
  - Competition with therapeutics (cheaper)
  - Economic interventions to bridge the pre-clinical to clinical gap
  - Public-private collaboration
  - Proof-of-principle evidence and health economic analyses for vaccines reducing AMR
  - 'Valley of death'
    - AMR funds not given to vaccine field
      - Increase funding for early-stage AMR-vaccine research
      - Incentives for private investment
    - High minimum costs and high risk
      - De-risking strategies
- Effective regulatory landscape
  - Expediate and harmonize regulatory approval processes
    - Collaboration with regulators
      - Develop regulation needed for shared biobanks
  - Lack of correlates of protection
- Vaccines prevent infections in livestock and AMR emergence
  - Animal and animal derived food trading regulations
    - More readily available DIVA vaccines
  - Livestock vaccines aren't cost-effective
    - Incentives to pull public health market into the animal space
  - Funding and frameworks for animal vaccines
- Vaccines reduce the burden of infection
  - Lack of target population identification
    - Collect data on infection profiles and patient demographics
  - Lack of uptake for existing vaccines
    - Prioritize vaccines which will have the greatest impact on reducing AMR burden
      - Prioritize risk groups
      - Research innate immune training and therapeutic vaccines

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