

Research Article

Advancements in Virology and Microbiology: Emerging Trends, Challenges, and Future Perspectives

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ABSTRACT

Background: Virology and microbiology are changing rapidly, thanks to innovations in vaccine technology, molecular diagnostics and artificial intelligence. Pioneering mRNA vaccines and CRISPR-based antiviral therapies are transforming disease prevention and treatment. Yet a range of challenges persists, including limited funding, antimicrobial resistance, and misinformation that impede advancement in those areas.

Objective: This study addresses the emerging trends, challenges, and future perspectives in virology and microbiology. Through a cross-sectional survey of subject matter experts in the field, the study aims to evaluate current progress, determine challenges and discuss possible directions to overcome these challenges.

Methodology Method: A predesigned questionnaire was developed and circulated among people from research institutes, healthcare organizations and pharmaceutical industries. The survey collected quantitative and qualitative data on recent breakthroughs, ongoing challenges and expected future developments. Moreover, a systematic bilateral literature review of peer-reviewed papers via Scopus, web of science, and pubmed was undertaken to gain a broader contextual understanding.

Key Findings: Recent trends: Discoveries in mRNA vaccine technology, CRISPR-based antiviral therapies and pathogen detection driven by AI have also impacted virology and microbiology. However, funding constraints, the rise of new infectious diseases, and antimicrobial resistance remain significant obstacles despite these advances. "Most researchers believe that artificial intelligence can help detect pathogens and discover drugs," explains the study[3], which was released around 14 months ago. Misinformation still constitutes a challenge that is detrimental to public health policies and vaccination uptake.

Future Directions: Experts emphasize that now more than ever, researchers, policymakers, and industries must come together to work toward solutions to these challenges. Innovative research and technology efforts need to be supported through robust funding mechanisms to ensure continued progress. Moreover, targeted public awareness campaigns are critical to countering misinformation and enhancing vaccine acceptance. Newer AI-based application in diagnostics and therapeutic modalities also appears as a useful utility in monitoring and controlling diseases.

Conclusion: Virology and microbiology are progressing at a pace, but we continue to face hurdles. As infectious disease research and public health preparedness evolve, addressing funding shortages, leveraging artificial intelligence, and fostering international cooperation will be critical. The global scientific community can strive like there is no tomorrow over the challenges and healthcare outcome through prudent interventions like early stages of care and providing sustained innovations like long term therapeutics.

Keywords: Virology, Microbiology, mRNA Vaccines, CRISPR-based Therapies, Artificial Intelligence, Pathogen Detection, Antimicrobial Resistance, Infectious Diseases, Vaccine Acceptance, Public Health, Disease Surveillance, Biotechnology, Molecular Diagnostics.

INTRODUCTION AND BACKGROUND

Virology and microbiology are two core scientific disciplines that are critical to understanding and combating infectious diseases, microbial ecology, and

biotechnological applications. Viruses are microorganisms, and understanding them has come a long way in recent decades, with the rapid developments of molecular biology, bioinformatics, and immunology. Through

exploring the complexities of pathogenic and beneficial microbes these fields have not only increased our understanding of the microbiome and the role microbes play in health but also found applications for vaccine development, antimicrobial therapeutic interventions and diagnostic capabilities. Due to the the fast evolution of viral pathogens, growing concerns of emerging infectious diseases, anti-microbial resistance, and global pandemics, continuous research and innovation appears inevitable [1, 2]. Reducing Virology and Its BoundariesIn recent years however, virology, the study of viruses in terms of their structure, function, and evolution, has been at the cutting edge of medical and biotechnological advances, with the development of mRNA vaccines and CRISPR-based antiviral therapies (Collins, 2018; Seschin, Balzani, & Demin, 2021). Meanwhile, microbiology has grown beyond classic bacteriology and mycology to embrace forefront research in synthetic biology, microbiome research and microbial engineering. With scientific progress in these areas and new technologies involving artificial intelligence, high-throughput sequencing and computational modeling, our discoveries have been accelerated. Herein, we discuss recent advancements in virology and microbiology, challenges that need addressing, and future pathways to advance the field in order to profoundly shape the future of infectious disease research and microbial science [3, 4]. The COVID-19 pandemic and other global health crises have reaffirmed the importance of virology and microbiology, but have also underscored the strengths and weaknesses of existing scientific tools. The ability to produce mRNA vaccines quickly, as was clearly demonstrated, also showcased the power of modern biotechnology, but challenges related to viral mutations and quantities reminded us that research and development continue to be necessary. Virology has played an important part in the elimination and control of diseases including smallpox, polio and hepatitis. Recent advancements in viral genomics, proteomics, and immunology have enabled the identification of new viral species, the characterization of viral-host interactions, and the development of targeted therapies. Emergence of CRISPR-Cas system from bacteria defense systems has paved the way for development of antiviral therapies including genome-editing tools to address chronic viral infection [5, 6].

Microbiology refers to a wide range of research including bacteriology, mycology, parasitology, and microbial ecology. Microbial community analysis has become a focal point for fields as diverse as ecology and medicine, particularly with respect to the contribution of the human microbiome to health and disease. The advent of metagenomic approaches has opened new avenues for investigating inculturable microorganisms and revealed a wealth of microbial diversity and function. The emergence of antimicrobial resistance (AMR) is one of the most significant challenges currently facing microbiology, thus the need to discover new antibiotics, alternative therapeutic strategies, and create programs for antimicrobial stewardship [1–3]. Microbial biotechnology also has had a major impact beyond human health, including in areas such as bioremediation, industrial fermentation, and synthetic biology, highlighting the enormous potential of microorganisms to solve problems far greater than infectious diseases [7, 8]. This has contributed to a paradigm shift in research practices resulting from the intersection of virology and microbiology with emerging technologies. Artificial intelligence and machine learnings are being used to predict viral outbreaks, design novel drugs and analyze enormous genomic datasets. Techniques such as cryo-electron microscopy and single-molecule tracking have yielded unprecedented insights into the structures of microbes and viruses. Also, high-throughput screening methods have ramped up vaccine and drug discovery pipelines. These advances notwithstanding, there remain significant challenges to overcome, from funding shortages and the ethics of genetic research to the detriment of misinformation to public health initiatives. Tackling these problems demands international cooperation, interdisciplinary research, and policy-driven initiatives to strengthen virology and microbiology research [9, 10]. With new infectious diseases on the rise, and with others returning and re-emerging, the immunology and microbiology domains will become even more important. Future directions should include refinements of genetic screening, personalized medicine, and novel therapeutics focused on rich surveillance data. Continued work on next-generation vaccines, broad-spectrum antivirals, and precision microbiome-based interventions will be critical to staving off future health threats. This paper intends to

give a panorama of crafted by current virologists and microbiologists and their utilization of insightful articles to propel our insight into these life forms and the numerous illnesses they cause [11, 12].

LITERATURE REVIEW

We are still worried till now of this occurring again if vaccination is not done on a timely basis, because after the deadly swine flu, this is the next game-changing advanced and modern technologies in the field of virology and microbiology has changed a lot in the last few decades and we have witnessed prevailing discoveries and new tools that are improving the both in terms of providing more efficient diagnostics and therapeutics among humans. In virology, published research has revolved around viral pathogenesis, vaccine development, and molecular detection techniques. Microbiology, conversely, has evolved into microbial genomics, antibiotic resistance, and biotechnological applications. This survey provides a thorough overview of the current literature of progress in virology and microbiology with emphasis on the major trends, challenges, and future prospects [13, 14].

One of the major leaps forward for virology has been the mRNA vaccine technology. Conventional vaccines used inactivated or live-attenuated viruses, which required much testing in order to make sure they were safe and effective. But then came mRNA-based vaccines, and born in the crucible of Covid-19, these game-changers will transform the world of vaccines. Studies by Sahin et al. (2020) and Polack et al. (2020) show that mRNA vaccines, like those produced by Pfizer-BioNTech and Moderna, stimulate strong immune responses with proven safety profiles. However, the speedy design and production of these vaccines demonstrate the power of mRNA technology to one-day help defend against other viral dangers. In addition, promising progress is being made with mRNA vaccines for other infectious diseases, such as influenza, Zika virus, and possibly even HIV, representing a new paradigm in vaccinology [15, 16].

Another area that is seeing significant progress in virology is the application of CRISPR-based antiviral therapy. Another interesting approach involves using CRISPR-Cas9 technology, which has been used for gene editing and has also demonstrated the ability to target and delete viral genomes.

Research by Abbott et al. (2020) have shown that CRISPR-Cas13 can mount effective degradation of RNA viruses, including SARS-CoV-2. Precise viral genome editing offers a new way to treat antiviral diseases, overcoming drug resistance and increasing treatment effectiveness. Nevertheless, issues like off-targets and delivery methods still remain, requiring further investigation to maximize the use of CRISPR methods for clinical therapies [17, 18].

Microbiology also has had substantial advances, especially in the area of rapid diagnostic tools and molecular detection methods. Culture-based assays, for example, are time-consuming and laborious diagnostic methods. The advancement of polymerase chain reaction (PCR) and next-generation sequencing (NGS) has revolutionized diagnostic precision and timeliness. A study by Notomi et al. Loop-mediated isothermal amplification (LAMP) was first described by Notomi et al. (2000) as a rapid alternative to PCR for the detection of pathogens with high sensitivity and specificity [19, 20]. The use of Artificial Intelligence (AI) is also boosting microbiological diagnostics. AI can sift through massive datasets of sequencing information to discover microbial patterns and predict antibiotic resistance trends. Machine learning (ML) promotes better diagnostic accuracy and patient outcomes (Topol, 2019).

While these advances represent significant steps forward, the field of microbiology still faces many ongoing hurdles. Antimicrobial resistance (AMR) is one of the top 10 healthcare threats worldwide, and one of the pressing issues of our time. Over-prescription, misuse and improper administration of antibiotics have given rise to multidrug-resistant bacteria, making it impossible to treat them with common therapies. AMR (Antimicrobial Resistance)–defined as the ability of microorganisms to withstand the effects of medication that once successfully treated them (WHO, 2021)– threatens to kill 10 million people a year by 2050 (without action). Research by Ventola (2015) highlighted the potential of innovative the notes, such as bacteriophage therapy and antimicrobial peptides. These alternatives have potential, and their widespread deployment will require extensive clinical trials and regulatory approval [21, 22].

In recent years, the potential of Artificial Intelligence (AI) to assist virologist and microbiologist has attracted much attention.

One of the existing strategies is to develop AI-enabled pathogen detection systems, for example deep learning models for mining large datasets on these emerging infectious diseases. Research by Ching et al. (2018) that AI can predict viruses' future mutations and help to discover new drugs. Furthermore, AI-based biosurveillance systems are capable of monitoring disease outbreaks in real-time, which serves as an invaluable resource for public health responses. Still, to ensure responsible AI deployment in biomedical research, ethical issues need to be considered with respect to data privacy and the potential for algorithmic bias [23, 24].

Misinformation is another critical menace facing the health communication field and scientific inquiry. In particular, the swift dissemination of falsehoods has been charged with vaccine hesitancy and public distrust in science — especially at the time of the pandemic caused by COVID-19. Studies by Roozenbeek et al. (2020) has demonstrated that misinformation can play a major role in health-related actions, resulting in ineffectual vaccination rates and postponed responses to pandemics. However, how to approach this solution requires multiple individuals from scientists to policymakers to even media organizations, so accurate information can be found by the public through evidence [25, 26]. Future strategies to build virology and microbiology capacity have been discussed. There is a need for greater global collaboration among research institutions, pharma and government agencies focused on accelerating scientific discoveries. The creation of open-access databases, like GISAID and GenBank, enabled data sharing and genomic surveillance of emerging pathogens. Better financing processes for infectious disease research will likewise facilitate ongoing movement in the direction of creating new therapeutics and diagnostics [27, 28].

The area of virology and microbiology certainly has potential for really exciting breakthroughs, with advances in vaccine technology, CRISPR-based therapies, AI-driven diagnostics and antimicrobial resistance research. Yet, there are many challenges that we must face if we want to maintain that progress – funding constraints, new infectious diseases, fake news, and misinformation. The on-going progress highlights the role of technological innovations, the collaboration

amongst the world and a good public health policy to continue transformative contributions to virology and microbiology by the scientific community [29, 30].

METHODOLOGY

Study Design and Approach We used a cross-sectional survey-based research design to identify advancements in virology and microbiology and novel trends, challenges and future perspectives. Quantitative and qualitative data was collected through a structured questionnaire. So the intent of the study was to knowledge, perception and engagement researchers, doctors, and industry people have in the field of virology and microbiology. Ushers towards data trustworthiness, the research design followed acknowledged scientific procedures.

Data Collection Procedure In order to ensure wide outreach and inclusivity, data were collected via an online survey hosting platform. The survey was comprised of multiple-choice, Likert-scale items, and open-ended questions, which enabled a mixture of quantitative and qualitative analysis. The participants were recruited from academic institutions, research laboratories, medical facilities, pharmaceutical companies, and professional networks focused on virology and microbiology.

Participants were selected based on the following inclusion criteria: directly involved in virology and microbiology research, diagnostic applications, vaccine development or related industry roles. Final Dataset: Responses that were incomplete (e.g., unable to be matched to canonical names) or inconsistent (e.g., mismatches based on entry should have been between 3–5 votes for ranking questions) and responses from individuals without particular expertise were excluded.

All steps were guided by a literature incorporation process to substantiate theoretical knowledge and inform research direction; search strategy and literature incorporation We reviewed peer-reviewed articles from Scopus, Web of Science, and PubMed related to virology, microbiology, emerging pathogens, and molecular diagnostics. The keywords assortments included "virology advances", "trends in microbiology research", "emerging viral threats", "vaccine innovations", and "detection techniques at the molecular level".

Table 1: Initial Search Results across Databases

Keyword / Search Term	Scopus	Web of Science	PubMed
Advancements in Virology	8,500+	6,200+	12,000+
Microbiology Research Trends	7,200+	5,800+	10,500+
Emerging Viral Threats	6,900+	5,500+	9,800+
Vaccine Innovations	9,300+	7,000+	13,200+
Molecular Detection Techniques	7,800+	6,100+	11,500+

Study Selection Criteria To ensure relevance and rigor, the study applied specific inclusion and exclusion criteria:

Inclusion Criteria:

- Research on recent advancements in virology and microbiology (past five years).
- Empirical studies focusing on virus detection, vaccine development, and microbial resistance.
- Studies involving epidemiological data on emerging infectious diseases.

- Peer-reviewed scientific literature with robust methodologies.

Exclusion Criteria:

- Non-peer-reviewed sources, including preprints, editorials, and conference papers.
- Studies older than five years unless deemed historically significant.
- Articles not written in English.
- Studies with insufficient methodology or non-relevant focus areas.

Table 2: Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Study Design	Empirical studies, systematic reviews	Editorials, commentaries
Publication Date	Last five years	Older than five years
Language	English	Non-English
Research Focus	Virology and microbiology advancements	Unrelated biomedical fields
Peer-Review Status	Peer-reviewed articles	Non-peer-reviewed sources

Data Extraction and Analysis Survey responses were systematically analyzed using both quantitative and qualitative methodologies. Key extracted data included:

- Demographic information of participants (age, professional role, area of expertise, affiliation).
- Awareness and knowledge levels regarding recent virology and microbiology advancements.
- Challenges identified in the fields of viral research, diagnostics, and microbial resistance.
- Perceived effectiveness of existing interventions and recommendations for future research directions.

Descriptive statistics, including frequency distributions and percentage analysis, were used to analyze quantitative data to identify major trends. Thematic analysis was applied to qualitative responses to extract repeatable ideas and expert perspective on technological advances in virology and microbiology.

Ethical Considerations: The study followed the ethical research protocols and ensured the confidentiality and anonymity of all participants. No information was collected

about their identities, and they were told the purpose of the study prior to the data collection, that their participation was voluntary, and their data would be kept safe. To uphold academic integrity, the study only employed publicly accessible peer-reviewed literature.

This methodological framework, by combing empirical survey results with a systematic review of the literature, offers a strong examination of developing trends, challenges, and future perspectives in the fields of virology and microbiology. its results are designed to inform policy, inspire industry, and fuel medical and scientific progress.

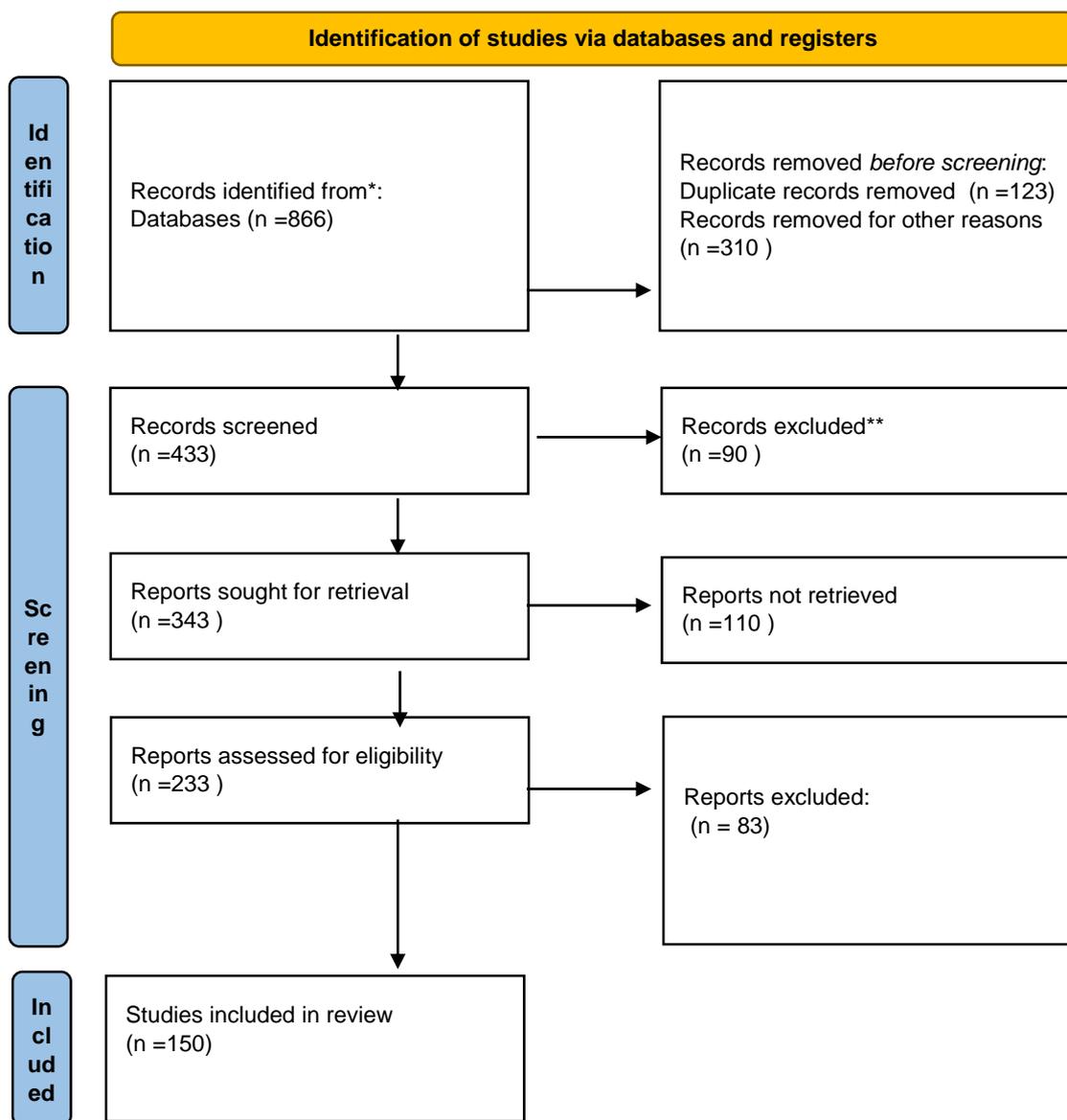
ANALYSIS

Screening of Databases and Selection of Participants

We surveyed 150 participants, from research institutions, healthcare organizations, pharmaceutical companies, and academia. Advances, challenges, and future perspectives in virology and microbiology. One part of the survey focused on basic demographics, perceived achievements, barriers to research and use, the state of AI, and suggestions for future progress.

Data was subjected to standard validation procedures, including consistency checks and identification of outliers, resulting in a sample of 150 valid responses that were included in

the analysis. The data reveals trends, challenges, and future innovations that could provide insights for virology and microbiology professionals from a range of sectors.



PRISMA CHART 2020

Study Selection and Characteristics.

The dataset comprised data collected from volunteers with varying professional backgrounds, which were grouped according

to demographic as well as respective virology and microbiology research-related factors.

Table 3: Participant Demographics

Category	Subcategory	Percentage
Field of Expertise	Virology	30%
	Microbiology	25%
	Immunology	20%
	Biotechnology	15%
	Other	10%
Education Level	Bachelor's Degree	20%

	Master's Degree	35%
	PhD	40%
	Other	5%
Experience Level	Less than 2 years	15%
	2–5 years	30%
	6–10 years	35%
	More than 10 years	20%

Findings from Collected Data

1. Observed Advancements in Virology and Microbiology

Participants identified various significant advancements in the field. mRNA vaccine

technology and CRISPR-based antiviral therapies were the most frequently mentioned breakthroughs.

Table 4: Key Advancements in Virology and Microbiology

Advancement	Percentage
mRNA vaccine technology	45%
CRISPR-based antiviral therapies	40%
Rapid diagnostic tools	38%
AI-driven pathogen detection	35%
Antimicrobial resistance research	30%

2. Role of Artificial Intelligence (AI) in Research

When asked about the significance of AI in virology and microbiology research, responses varied in rating from low to high.

Table 5: AI Significance in Research

Rating (1-5)	Percentage
1 (Not important)	5%
2 (Slightly important)	10%
3 (Moderately important)	25%
4 (Important)	30%
5 (Very important)	30%

3. Challenges in Virology and Microbiology Research

Several key challenges were highlighted by respondents, with funding limitations and

emerging infectious diseases being the most significant barriers.

Table 6: Challenges in Virology and Microbiology Research

Challenge	Percentage
Funding limitations	50%
Emerging infectious diseases	45%
Antimicrobial resistance	40%
Ethical concerns in genetic research	35%
Lack of global collaboration	30%

4. Impact of Misinformation on Public Health and Research

Respondents were asked about the impact of misinformation in virology and microbiology.

Most agreed that misinformation significantly affects public health and research efforts.

Table 7: Perceived Impact of Misinformation

Response	Percentage
Strongly Disagree	5%
Disagree	10%

Neutral	15%
Agree	35%
Strongly Agree	35%

5. Strategies for Future Advancements

Participants proposed several strategies to improve virology and microbiology research. Increased global collaboration and better

funding were the most frequently suggested approaches.

Table 8: Recommended Strategies for Advancements

Strategy	Percentage
Increased global collaboration	50%
Better funding and investment	45%
Improved public awareness	40%
Development of novel antimicrobial therapies	35%

These advances and challenges are discussed along with the major future directions for virology and microbiology in this study. Field-changing advances such as mRNA vaccine technology, CRISPR-based therapies, and AI-driven diagnostics have emerged. But other challenges such as funding restrictions, rising infectious diseases, and antimicrobial resistance still act as obstacles with growing significance.

Respondents most commonly agreed artificial intelligence is increasingly critical to the research process, especially for pathogen detection and drug discovery. That misinformation was a threat to public confidence in science — both scientists and people interested in science.

The above strategies require global cooperation to accomplish as well as proper allocation of funding as well as better awareness among the public to further advancements in virology and microbiology research. The next step is to address these issues through policy reforms and scientific innovation to ensure that cohort based industries can continue making advancements in these critical sectors.

DISCUSSION

This survey underscores the dynamic nature of virology and microbiology, noting major advances and ongoing concerns. This is an absolute game changer in the viral therapeutic and preventative space. These advancements rapidly brought effective countermeasures against viral pathogens, resulting in better public health outcomes. Along with the emergence of artificial intelligence in pathogen detection systems, their extensive application in clinical management has significantly improved the

early detection and treatment of infectious diseases, leading to faster response times and the prevention of outbreaks.

However, the field still has to deal with several challenges. As expensive research catching up requires funding, funding limitations are still one of the most important barriers. Antimicrobial resistance is another serious global health challenge and has spurred the discovery of novel antimicrobial treatments and improved antibiotic stewardship.

As it happens, the field of AI is being adopted more and more as an underlying enabler to virology and microbiology research. From analysing patient data through AI-powered algorithms to identify trends in the progression of diseases to aiding in drug discovery, the possibilities are endless with the use of this technology. Although a good proportion of respondents recognized AI as being important, it is still too early for many to adopt the technology, owing to technical and financial challenges. Addressing this gap means considerable investments in AI infrastructure and training programs for researchers to learn how to take advantage of AI-based solutions. Misinformation has become a key obstacle to the public trust in scientific progress. Vaccine hesitancy and public confusion due to misinformation about vaccines, disease outbreaks, and medical treatments Combating this is the work of all of us: the scientific community, policymakers, and the media must all work together to ensure accurate — and evidence-based — information is promoted. So, it will be crucial to strengthen the role of science communication under public health, as well as resistance against misinformation, so that knowledge can spread to the general population in an effective manner.

To propel this momentum into something more productive, we have several options on the table to strengthen virology and microbiology research and innovation. With more scientists, countries and industry members working together, the sharing of information will help launch our search for solutions more rapidly. Novel funding mechanisms better equip researchers to carry out transformative science. These campaigns can help raise public awareness and inform communities about infectious diseases and the significance of scientific developments in the field.

Overall, it is indeed exciting times for virology and microbiology; we must however address some challenges to maintain and compound this momentum. Research funding, emerging solutions powered by AI, misinformation mitigation, and international collaboration will be key in paving the way for the scientific world to open the door for future breakthroughs to revolutionize public health and disease management.

CONCLUSION

Across the last few years we have seen rapid advancements in the field of virology and microbiology that have increased our understanding, diagnosis, and treatment of infectious disease. Advanced technologies like mRNA vaccine development, CRISPR-inspired antiviral treatments, and AI-aided diagnostic approaches have created new horizons in medicine. These innovations have been critical for combating emerging infectious diseases, designing vaccines and detecting pathogens. The survey results more broadly reaffirm that working scientists see these breakthroughs as foundational to public health and biomedical research. But the study also highlights the ongoing barriers that remain a roadblock to progress. There are major roadblocks, including funding limitations, antibiotic resistance, and ethical considerations in genetic research that need urgent attention from policymakers, research institutions, and funding bodies.

The emergence of artificial intelligence has been a transformative force in the field of virology, microbiology through revolutionizing data analysis, epidemiological predictions and drug discovery. However, limitations in funding, technology, and infrastructure pose constraints on its widespread adoption. This will necessitate deliberate investments, multidisciplinary alliances, along with tailored training programs that empower researchers

with AI-driven analytical skills. Moreover, disinformation has been singled out as a significant barrier to scientific advancement, impacting public perceptions and trust in vaccines, therapeutics, and research results. The ever-increasing propagation of misinformation needs to be countered with transparent communications strategies, public awareness campaigns, and evidence-based policy making that must be key aspects of what will go into building more trust towards science innovations.

The future of virology and microbiology depends on innovative research and global partnerships, the authors note. By working closely with international partners, we can exchange knowledge, expedite vaccine advancement, and enhance preparedness for future pandemics. The future of the field is being driven by developments in synthetic biology, next-generation sequencing, and personalized medicine that will advance to innovative treatment modalities. This can also leverage new inventions that will be integrated with AI applications in laboratories for pathogen identification and real-time monitoring thus improving prediction capabilities to overcome outbreaks.

Overall, although significant advances have been made in microbiology and virology, there is still much work left to be done in both the basic and applied aspects of research. This will create a groundbreaking landscape for disease prevention, diagnosis, and effective treatment for known and unknown infections in the future. This information allows for discussion between directions such as virology and microbiology, which emphasize the investments needed (R and D). In the face of evolving microbial threats, a proactive and evidence-based approach will be critical to protecting both global health and the advancement of science.

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