Food and Agriculture Organization of the United Nations

World Health Organization

World Organisation for Animal Health

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Report of the Quadripartite technical meeting, Riyadh, Saudi Arabia, 27–29 November 2023

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Contents

Acknowledgements

Quadripartite Secretariat:

Food and Agriculture Organization of the United Nations (FAO) headquarters: Gisella de Oliveira Dias da Silva, Lidewij Wiersma, Orr Rozov, Zelalem Tadesse, Baba Soumare

United Nations Environment Programme (UNEP): Julian Blanc and Geetha Nayak

WHO Regional Office for the Eastern Mediterranean: Amal Barakat, Hala Abou El Naja, Heba Sobhy Ibrahim Mahrous

WHO headquarters: Abdullah Al Sayafi, Alice Simniceanu, Josine Umugwaneza, Judith Mandelbaum-Schmid, Maria Van Kerkhove, Ruth McCabe, Sally Berman, Sophie von Dobschuetz, Suzanne Kerba.

World Organisation for Animal Health (WOAH): Gounalan Pavade

Saudi Arabia:

Public Health Authority: Ezzuddin Ahmad Okmi, Emad Almohammadi, Mukhtar Fiyah Althiyabi, Faten Jaber Althobaiti, Turki Abdullah Alzahrani, Amirah Ahmed Sultan; contributions include those made to the technical concept of the meeting as well as the writing of the report

Ministry of Health: Haleema Ali Mohammed Alserehi; contributions include those made to the technical concept of the meeting as well as the writing of the report

Weqaa Center: Ali Aldoweriej, Omer Alnuwais

Additional organizers and rapporteurs:

Malik Peiris (Hong Kong University); Cassie Jones, Julie Sinclair (United States Centers for Disease Control and Prevention [collaboration preceded 20 January 2025]); Abdullah Hassan Alsheri, Mahmoud Aldouhki, Shaymah Adulaziz Aldawidh (Public Health Authority Saudi Arabia)

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1. Background: Middle East respiratory syndrome

Since its identification in the Kingdom of Saudi Arabia and Jordan in 2012, Middle East respiratory syndrome coronavirus (MERS-CoV) has continued to pose a significant public health, health security and economic threat to the global community. MERS-CoV has an animal reservoir–the dromedary camel–in which the virus causes little or no disease signs. [1] At the time of this meeting, 2 608 cases of human infection had been reported to the World Health Organization (WHO) [2], predominantly from countries in the Arabian Peninsula, and cases have been exported to all regions of the globe. MERS-CoV is one of three high-impact zoonotic coronaviruses that have emerged in recent years and is included in the WHO list of pathogens with epidemic and pandemic potential, prioritized for research and development (R&D) in emergency contexts. [3] Other recently emerged coronaviruses with pandemic potential include SARS-CoV, which emerged in late 2002 and spread to 29 countries before the epidemic ended in July 2003, having caused more than 8 000 infections and 774 deaths; and SARS-CoV-2, first reported in December 2019 and responsible for over 775 million reported human cases and over 7 million deaths reported globally. [4]

Over the past years, the Food and Agriculture Organization (FAO), WHO and the World Organisation for Animal Health (WOAH) have regularly brought together public health and animal health experts from affected and at-risk countries, academic scientists and subject matter experts of high- threat respiratory pathogens to review the latest scientific evidence on MERS-CoV and enhance collaboration across all sectors worldwide. Following a regional international scientific meeting on MERS-CoV organized by the WHO Regional Office for the Eastern Mediterranean in Cairo in May 2015 [5], and as part of continuing efforts to address MERS-CoV, FAO, WHO and WOAH convened the first Tripartite Global Technical Meeting [6] in Geneva, Switzerland from 25-27 September 2017 where 130 attendees participated from the ministries of health and agriculture of affected and at-risk countries, academia and subject matter experts. This was followed up with an online Tripartite meeting entitled Global Technical Meeting on MERS-CoV and Other Emerging Zoonotic Coronaviruses [7], held from 15 to 16 November 2021.

In continuation of these efforts, a global technical meeting was held in Riyadh, Saudi Arabia from 27 to 29 November 2023 and organized as a Quadripartite event by including the United National Environment Programme (UNEP). Co-organizers of the meeting were WHO Regional Office for the Eastern Mediterranean and the Saudi Public Health Authority (PHA), with support from the Saudi Ministry of Health. This report presents the summary and findings of this technical meeting.

This report is an overview of the meeting's presentations and discussions and does not necessarily reflect the views of the convening organizations.

2. Rationale and objectives for the November 2023 meeting

Attention to MERS understandably declined during the most intense phase of the COVID-19 pandemic. The organizers of the meeting sought to sharpen the focus on MERS-CoV and other emerging zoonotic coronaviruses and bring together global stakeholders to share the latest findings from laboratory and field research as well as lessons learned and good practices in affected countries. Organizers were conscious as well of the rapid scientific advances made throughout the COVID-19 pandemic in the understanding, diagnosis, prevention and treatment of diseases caused by coronaviruses; and that such advances and capacities may now in turn be applicable to initiatives on MERS-CoV.

The experiences and lessons learned by countries and the global community with influenza, SARS-CoV, MERS-CoV and most recently SARS-CoV-2 have informed updated pathogen-agnostic elements of respiratory pathogen pandemic preparedness, including WHO's Preparedness and Resilience for Emerging Threats (PRET) initiative [*8*, *9*] and checklist for respiratory pathogen pandemic preparedness planning. [*10*] The COVID-19 pandemic has forced the world to re-evaluate outbreak and pandemic preparedness, including collaborative surveillance, community protection, safe and scalable care, access to countermeasures and emergency coordination, to retain a state of readiness.

More can be done to limit spillover infections of MERS-CoV at the animal-human interface using a One Health approach. This requires continued strengthening of community engagement, multisectoral collaborations and efficient data sharing processes, surveillance in dromedaries and in persons in direct contact with dromedaries, development of One Health surveillance with adequate diagnostic capacity in animal and public health sectors, and accelerated developments of effective vaccines and human therapeutics.

241 participants from 51 countries attended the by-invitation-only meeting. Invited stakeholders included representatives from ministries of health, ministries of agriculture and ministries of environment in affected and at-risk countries, MERS-CoV and zoonotic coronavirus (zCoV) subject matter experts and researchers, funding agencies, industrial partners and representatives from FAO, UNEP, WHO and WOAH at headquarters, regional and country levels.

Objectives of the meeting included the following:

- Report on the implementation of past meeting recommendations, latest scientific findings and ongoing research, country experiences and lessons learned on MERS-CoV since the last Global Technical Meeting in 2021. [*7*]
- Facilitate coordination and communication between relevant sectors to ensure the implementation of the One Health approach for MERS-CoV and emerging zoonotic coronaviruses: 1) preparedness, prevention, readiness and control; 2) surveillance activities, diagnostic

approaches and interpretation of results; and 3) intervention measures, including potential vaccination of dromedaries and humans, community engagement and risk communication.

- Review and apply lessons learned from COVID-19 for the prevention and control of MERS-CoV and other emerging zoonotic coronaviruses, building on the discussions of past global technical meetings.
- Update strategies, tools and steps to restore, develop and maintain MERS-CoV prevention and control efforts in affected and at-risk countries, including at the animal-human-environment interface and through multi-pathogen surveillance.
- Identify priority actions and future research needs for the continued advancement in the prevention and control of MERS-CoV and other zoonotic coronaviruses.

Above all, participants sought to reach consensus on priority actions and future research needs for the continued advancement in the prevention and control of MERS-CoV and other zoonotic coronaviruses.

3. Priority research needs identified by meeting participants

Numerous participants indicated that the focus on MERS suffered a setback in the context of the COVID-19 pandemic, diverting global attention from this crucial area of work. Participants emphasized the importance of redirecting efforts towards MERS by prioritizing funding, political commitment and active engagement from the scientific community to address the key research priorities. Considering past and ongoing research as well as countermeasure development outlined in the WHO Research and Development (R&D) Blueprint, participants identified outstanding gaps and put forward priority research needs.

Surveillance/genomics

Increased geographic coverage and temporal continuity. Ongoing and recent efforts in this area were presented during the course of the meeting (mostly unpublished) and include recent field surveys in occupationally exposed humans conducted by WHO in Pakistan and Somalia; camel surveillance implemented by FAO in Egypt, Ethiopia, Jordan, Kenya and Oman; research projects focusing on occupationally exposed humans and/or camels in Jordan, Kenya and Nigeria; and routine surveillance efforts in humans and camels in Saudi Arabia and the United Arab Emirates. There remains a need, however, to increase geographic coverage for and temporal continuity of MERS-CoV surveillance in humans and camels, to obtain novel sequences and contemporary isolates for characterization and risk assessment and estimate the extent of MERS-CoV circulation, including evidence of zoonotic spillover, in Africa and Asia. This is especially important in countries with large camel populations that have not conducted any surveillance to date.

Sharing of sequence data and isolates. The importance of real-time monitoring of the diversity and evolution of circulating MERS-CoV clades and strains in different epi-zones was brought up repeatedly by participants throughout the meeting, and the need for providing incentives for the timely sharing of sequence data and isolates was highlighted. The clades currently circulating are clade B in the Arabian Peninsula and clade C in Africa. However, it was noted that the last full genome sequence data upload to a public database dates back to early 2020, and that most research was actually conducted on clade A isolates, a clade that has been extinct for some time, likely since 2016. Genetic information and isolates of currently circulating strains are urgently needed for virus monitoring and molecular characterization and to increase relevance of research, including for therapeutics and vaccine development.

Burden of infection. Recent work by Mok et al. (2021) revealed that to estimate the true burden of infection among humans exposed to camels, serological and neutralization assays may not be sufficient and suggests testing for T-cell responses in addition. [*11*] This technique may help to shed light on the true zoonotic burden of MERS-CoV in Africa and Asia, where

human cases have not officially been reported to date. Additional research is needed, however, to confirm the validity of the testing method in different geographic contexts since Mok's study was conducted on a relatively small sample size and only in Nigeria. It is important to note that this additional test has to be planned from the onset of a study as appropriate samples need to be collected (peripheral blood mononuclear cells – PBMCs).

Cross reactivity/cross protection. Participants emphasized that cross-protection from MERS-CoV infection against SARS-CoV-2 or cross-reactivity (e.g. in serological assays) has to be further investigated as it may have implications for infection severity, transmission risk, and the interpretation of serology results.

Environmental surveillance. Exploring the application of environmental surveillance was suggested by participants, including surface sampling and wastewater surveillance in camel-dense locations such as farms, markets and slaughterhouses as well as hospitals. Applicability and relevance of wastewater surveillance in the context of MERS-CoV detection or monitoring was highlighted as an area to be further investigated.

Animal/human interface – One Health

Animal infection. Improved understanding of all factors that influence MERS-CoV shedding in camels is needed to anticipate periods of increased transmission risk and to better target mitigation measures. Participants highlighted that shedding routes, shedding intervals and the effect of (natural or vaccine-induced) immunity in modulating or eliminating shedding need to be better understood despite being a knowledge gap that had already been evidenced in previous meetings. For example, the shedding and therefore risk of MERS-CoV exposure through milk, meat, urine and feces is still not fully characterized. Evidence for periodic re-infection of camels was noted, but the reasons, factors and timelines for waning of immunity still need to be further investigated.

Human infection. Detection of asymptomatic and very mild human cases is needed to understand the true burden of disease. Participants suggested that this will require adapting approaches for screening of mild respiratory illness. The role of asymptomatic or mild human cases in onward human-human or even human-camel (reverse zoonotic) transmission has also not been quantified and needs further investigation.

Interface. Participants agreed that the different routes of camel-to-camel and camel-to-human transmission of MERS-CoV need to be better understood, as well as their relative importance. They put forward to identify and test non-pharmaceutical interventions for interrupting camel-to-camel and zoonotic transmission at the animal-human interface, as well as acceptable preventative measures targeting camels and their handlers. This will also require research on how to implement these in a cost-effective and socially acceptable way.

Testing of historical samples prior to 2012 is a cost-effective approach to investigating past disease dynamics in camels and human exposures.

WHO has been updating its Unity Study protocols for MERS-CoV investigations and studies that contain protocols for early investigations during a MERS outbreak as well as One Health investigations of zoonotic infections in humans and their camels. [*12*]

Community engagement

Social and behavioural sciences. Participants indicated that this area of research should focus on understanding the needs, perceptions (including risk perceptions) and capacities of communities at risk, the drivers and determinants of transmission and spillover and the factors that influence acceptance and uptake of population and environmental interventions, such as vaccine acceptance, including social-behavioral aspects. This includes studying the attitudes of at-risk populations towards vaccine

safety, side effects, trust in health authorities and access to information.

Anthropological research. Participants highlighted the need to identify culturally appropriate communication methods and engagement strategies that resonate with local beliefs, values and norms. This includes understanding the role of traditional healers, local customs related to animal husbandry and cultural practices that may affect the transmission of MERS-CoV.

Based on social-behavioral and anthropological evidence, participants recommended interventions to be co-developed and tailored with those at risk to shape risk perception, address uncertainties and build trust within communities. This would include research to identify effective ways to communicate risks and benefits and develop strategies to engage community influencers and empower communities to serve as partners in developing acceptable and workable solutions. Research should explore best practices for capacity building that can support community engagement and spillover prevention efforts.

Socioeconomic research areas. Risk communication and community engagement (RCCE) research areas related to MERS include studying the impact of the disease on health systems and the economic burden it imposes; assessing the role of social determinants of health such as income, education and occupation on disease spread and management; and examining the influence of trust in government and health authorities on public responses to RCCE initiatives.

Anthropological considerations in MERS-CoV RCCE should focus on culturally sensitive communication, addressing the needs of vulnerable groups and understanding community perceptions and responses. Participants emphasized that this will require a multidisciplinary approach that integrates social-behavioral and anthropological insights with public health strategies to enhance the effectiveness of RCCE initiatives.

Diagnostics and countermeasures

Vaccines

To date, there is no licensed vaccine available for either humans or camels; this remains a critical research gap.

Vaccines under study. Development of efficacious vaccines in both humans and camels is vital to MERS control for people at risk. As was discussed during the meeting, currently there is research and development for several MERS-specific and merbeco- and pan-sarbecovirus vaccines, but none of them has entered the stage of Phase II clinical trials yet. There are distinct challenges to obtaining licensure of both categories of vaccine, as noted below.

Animal models. Because of the low incidence and sporadic nature of MERS in humans, efficacy trials are currently not feasible, making data from appropriate animal models the only path towards licensure. Participants agreed that model development for SARS-CoV-2 could provide a roadmap for developing an optimal animal model for MERS-CoV.

Policy Considerations. Participants discussed the value of a proactive vaccination strategy versus a reactive strategy. Recent modelling research has shown that reactive vaccination of health-care workers in a hospital outbreak would avert more cases than a proactive strategy. For a robust proactive strategy in health workers, the vaccine would need to have high efficacy (>75%) and long duration of immunity. [*13*] However, a proactive campaign could be useful for groups who have routine exposure to camels, such as camel handlers and racers. A few research questions present themselves. Will people at risk get vaccinated, or, if there is a vaccine for camels, will owners opt to get their camels vaccinated? Combining a vaccine for MERS-CoV with a vaccine for a camel disease that is widely accepted and used (e.g. camel pox or brucellosis) could facilitate uptake. Reviewing and applying lessons learned from COVID-19 vaccination efforts in humans as well as vaccination strategies in animals for other high-impact diseases will

be crucial to the success of any MERS-CoV vaccination strategy.

Diagnostics

Inclusion of MERS-CoV in multi-pathogen tests. The emergence and co-circulation of diverse respiratory pathogens with similar symptomology has highlighted the importance of multiplex diagnostic tools for efficient and timely detection. This approach streamlines diagnostic processes and also contributes to early identification and containment of outbreaks. The significance of incorporating MERS-CoV into multi-pathogen rapid tests for enhanced routine surveillance was highlighted by participants, as was the importance of providing low- and middle-income countries affected by MERS with access to these tests. Addressing this gap requires collaborative efforts between virologists, microbiologists, diagnostic developers and public health agencies to ensure the comprehensive and adequate coverage of respiratory pathogens in diagnostic panels.

Updating MERS-CoV case definitions. The most recent comprehensive update to the MERS-CoV definition for humans from Saudi Arabia was in 2018. [*14*] Considering co-circulation of other respiratory pathogens with similar symptomatology, any changes in MERS clinical presentation and any novel traits of emerging MERS-CoV variants, participants suggested that the case definition for humans should periodically be refined to enhance early detection, diagnostic accuracy and more effective public health interventions. Despite not causing overt clinical signs in animals, MERS is a WOAH-listed disease in dromedaries, and a case definition was published for reporting confirmed MERS-CoV infection in dromedaries based on isolation of the virus or identification of viral nucleic acid specific to the virus (**Chapter 16.2 of the Terrestrial Code**).

Assessing accuracy of current diagnostics. Genetic evolution of MERS-CoV may require adaptation of current diagnostic targets and should inform development of future assays. [*15*]

Duration of antibody response to MERS-CoV. Understanding the duration of the antibody response to MERS-CoV for humans is essential for serosurveillance and vaccine development. Participants highlighted current research gaps in clarifying the longevity of antibodies post-infection as well as the need for confirming the validity of testing for T-cell responses. Conducting longitudinal studies to monitor antibody levels in recovered individuals will provide crucial insights into the durability of immunity.

Interpretation of ELISA positives in MERS-CoV surveillance. The enzyme-linked immunosorbent assay (ELISA) is a frequently used serological method for MERS-CoV surveillance; but interpretation of ELISA positives requires further investigation. Participants agreed that researchers should investigate how to differentiate between true positives, cross-reactivity with other coronaviruses and other potential false positives. Improving the specificity of serological tests will enhance the accuracy of MERS-CoV surveillance data, allowing for more reliable epidemiological assessments.

Therapeutics

Treatment is currently non-specific and supportive. To date, there is no specific treatment for MERS. In the absence of MERS-specific therapeutics, treatment of MERS patients is supportive and targeted to the patient's clinical condition. As is the case for COVID-19, MERS patients who are severely ill require critical care and oxygen. However, due to its affinity for the lower respiratory tract, MERS-CoV is prone to causing more severe disease, often with fatal outcome.

Therapeutics under study. A study in Saudi Arabia found that when people had early antibody responses, it helped reduce the mortality rate. [*16*] Participants agreed that this provides a rationale to conduct further research into whether antibodies from convalescent plasma or monoclonal antibodies might be a useful treatment despite a lack of evidence to date for effectiveness. Treatment with

nirmatrelvir/ritonavir to reduce the risk of hospitalization and death in MERS patients has promise but has not been assessed through clinical trials, which are difficult to perform because of the sporadicity of MERS cases.

The lack of a specific MERS treatment is a major research gap. Recent evidence has not yet been incorporated into updated clinical guidelines. For example, a randomized clinical trial of recombinant interferon beta-1b and lopinavir–ritonavir showed reduced mortality, especially if treatment was started within 7 days of symptom onset (MIRACLE trial, unpublished). Additionally, participants suggested that observational data on supportive care could be used to frame recommendations for the wider medical community. As is the case with vaccines, there are challenges to licensing and bringing to market a specific MERS treatment.

4. Proceedings of the meeting

The meeting was conducted with a mix of presentations, panel discussions, Q&A sessions, a poster session and discussion, round-table group work and an interactive networking session. In the final sessions of the meeting, participants broke out into groups to agree on a set of MERS research priorities and then stated how they could individually help address them and what they would need to do so (the outcomes of this session are summarized in Annex 1).

Welcome

The meeting was inaugurated with a welcome from Abduallah Al Quwizani, Chief Executive Officer of the Public Health Authority of Kingdom of Saudi Arabia; Rick Brennan, Regional Director for the WHO Regional Office for the Eastern Mediterranean; and Maria Van Kerkhove, acting Director of the WHO Epidemic and Pandemic Preparedness and Prevention Department. There were further opening remarks from the representatives of the Quadripartite Organizations: Baba Soummare, Global Manager of the Food and Agriculture Organization (FAO); Ayman Eltalouny, head of Saudi Sustainability Programme at the UN Environment Programme UNEP); and Gounalan Pavada, Chargé de Mission, World Organisation for Animal Health (WOAH).

Setting the scene

Speakers: Maria Van Kerkhove, WHO HQ, Switzerland; Malik Peiris, University of Hong Kong, Hong Kong Special Administrative Region, China

Summary

The technical part of the meeting commenced with an overview of the current understanding of MERS-CoV and the activities conducted by the Quadripartite, formally Tripartite (FAO, WHO, WOAH), over the years. The epidemic curve over the past 12 years reflects several outbreaks in humans, most of which occurred in Saudi Arabia, but also in the Republic of Korea (in 2015). A reduction in case reports has been observed during the COVID-19 pandemic, which may be explained by the initial focus of surveillance on COVID-19 and as a result of the mitigation measures implemented, which would also prevent onwards human-to-human transmission of MERS-CoV. It is of great concern that the spillovers from camels to humans are silent and often undetected. The infection is only detectable when affected high-risk individuals enter health care facilities. MERS is still a global threat, and gaps in surveillance and genetic characterization of the virus remain.

A brief overview of the activities conducted by the Quadripartite organizations thus far for MERS was presented, including the development of key guidance documents, such as the Muscat [*17*] (May 2014) and Doha [*18*] (April 2015) declarations. Several missions and trainings were conducted over the years, with focus on the One Health approach to be applied in the prevention, investigation and control of the disease. FAO, WHO and WOAH jointly developed a workplan for MERS under

the Tripartite agreement, including activities to strengthen preparedness and prevention for countries at risk, improve national capacities to detect, respond to and contain outbreaks when they do occur, improve the evidence base for guidance, and accelerate public health research and development for countermeasures like vaccines and human therapeutics. The WHO R&D blueprint has classified MERS as a priority pathogen for product development and in 2016 developed target product profiles for vaccines and therapeutics.

Achievements and advances made for MERS-CoV also lay the groundwork for the initial COVID-19 response – understanding of zoonotic coronaviruses, preparation of technical documents and implementation of trainings. In turn, it is essential that capacities developed and strengthened during the COVID-19 pandemic in surveillance, testing, sequencing, clinical care and infection prevention and control be maintained and sustainably financed, as part of overall pandemic preparedness.

While Africa hosts about 87% of the global camel population [*19*], there has not been any officially reported autochthonous human MERS case from the continent. This may be in part explained by a lack of surveillance activities, but studies comparing virus isolates from dromedary camels also found that clade C virus (circulating in Africa) viral replication levels and transmission efficiency is lower in camels than clade B virus (circulating in the Middle East). [*20*] This may explain why clade C remains prevalent only in Africa, although there is significant camel trade from African countries towards the Arabian Peninsula. If clade B should be introduced into the African continent, it may become the predominantly circulating strain which could lead to a serious public health problem. A major gap in our current understanding of the genetic make-up of circulating MERS-CoV strains and how the virus evolves over time was highlighted given that human and camel MERS-CoV sequences have not been shared with the international community since 2020.

Although seroepidemiological studies have been conducted in some African countries, there is limited evidence of previous infection in humans (mostly in camel herders). [*20, 21, 22*] It is likely, however, that infection in humans has been underestimated. This underlines the need for more seroepidemiological and virological studies and an increase in awareness, prompting targeted surveillance activities in camel-herding areas in Africa.

Plenary Session: Preparedness for coronaviruses using a One Health approach

Speakers: Baba Soumaré, FAO HQ, Italy; Emad Almohammadi, WHO MERS Collaborating Centre – Public Health Authority, Saudi Arabia; Naif Alharbi, Gulf CDC, Saudi Arabia; Amr Kandeel, Ministry of Health Egypt; Salim Uzzaman, Institute of Epidemiology Disease Control And Research (IEDCR), Bangladesh; Ana-Maria Henao-Restrepo, WHO HQ, Switzerland (by video)

Summary

The Kingdom of Saudi Arabia Public Health Authority presented on its functions as a WHO Collaborating Centre for MERS and its work drawing on the Kingdom's experience in managing MERS. Its activities include the development of evidence-based guidelines, supporting WHO in development and strengthening of surveillance and preparedness systems and acting as a WHO collaborating centre to build capacities and respond to and control MERS outbreaks.

The Gulf Center for Disease Prevention and Control reported on its work on early detection and notification of MERS-CoV and other zoonotic coronaviruses. This organization, which approaches its activities with a One Health focus, performs regional detection and risk management, makes practical recommendations and is building a dashboard for preparedness and early warning.

Egypt and Bangladesh presented their country experiences using a One Health approach

to coronavirus preparedness, including MERS-CoV. Egypt has developed a One Health governance structure to oversee and guide the implementation of agreed joint activities across sectors. In Bangladesh, a One Health approach has been practiced since 2008, following a series of avian influenza outbreaks in chickens that led to zoonotic spillover and human cases. [*23*]

The WHO R&D Blueprint centre presented on its aims to bolster global readiness and response to potential future epidemics and pandemics by expediting research on emerging disease threats, including those potentially caused by novel coronaviruses. WHO's methodology employs a viral family-centric approach, pinpointing representative viruses within a family as pathfinder viruses. This focused strategy aims to develop vaccines and treatments more rapidly and in doing so, address knowledge gaps applicable to other threatening viruses within the same family. There is growing endorsement of this approach, lauded for its ability to expedite research and encourage comprehensive studies on entire virus classes. This departure from an individual strain focus enhances the capacity to respond to unforeseen strains, zoonotic viruses and the potential emergence of a Pathogen X.

Plenary Session: Science-policy interface discussion on preparedness and One Health approach

Speakers: Abdullah Assiri, Ministry of Health Saudi Arabia (by video); Amr Kandeel, Ministry of Health Egypt; Maria Van Kerkhove, WHO HQ; Fatma Hussien Al Loghani, Ministry of Health and Prevention UAE; Christian Drosten, Charité Berlin, Germany

Summary

Panelists shared their global to national examples of successes and failures in translating science into useful policies in the context of One Health activities.

WHO presented difficulties in reshaping evidence-based guidance into policy during COVID-19, citing challenges in dealing with data gaps, low quality data and issues with misinformation. The Organization was accountable and had to communicate what was known, what was not known and what they were doing to address unknowns.

National examples included Germany, which during the first wave of COVID-19 seemed to have managed to maintain transmission at low levels due to measures the country implemented. This inspired public confidence that science could be trusted. However, a winter wave led to high mortality, in part, because of misinformation that was sometimes unintentionally supported by professional organizations.

When COVID-19 arrived in Egypt, difficulties were encountered in the implementation of its pandemic preparedness plan because of a lack of diagnostic kits and vaccines. This experience prompted planning for future stockage.

In the United Arab Emirates, policy challenges during COVID-19 arose from the involvement of five different ministries and a national authority for crises. Now scientists are seeking to engage with the country's political leadership through regular meetings.

Saudi Arabia has a long history of bringing scientists and policy makers together, dating back to the outbreak of Rift Valley fever in 2000. The MERS outbreak in 2012 introduced the concept of One Health in the country through real-life practice with human and animal health.

The lessons learned from past experiences played a crucial role during the COVID-19 pandemic, showcasing the importance of effective collaboration between scientists and policy makers. The tension between having poor or incomplete information and being asked to shape solid recommendations based on limited information was acknowledged. The importance of trust, transparency, regular and timely communication and a One Health approach emerged as key factors for building effective relationships at the science-policy interface.

Plenary Session: Conducting Risk Assessments for zoonotic coronaviruses to better target prevention measures; using strengthened national capacities from COVID-19 and MERS

Speakers: Gisella Dias, FAO HQ, Italy; Bernard Faye, CAMENET; Oyelola Adegboye, Menzies School of Health Research, Australia

Summary

Presenters explored the risks pertaining to MERS geographic expansion and introduction, associated with camel husbandry and trade. Clade B, which is currently present in the Arabian Peninsula and responsible for all officially reported human cases, has so far not been detected in Africa, where a different clade, C, is circulating in camel populations. The risk of clade B being introduced into this new region through movement of camels and their products or fomites has been assessed by FAO as negligible to low.

Climatic changes and aridification are leading to a geographic expansion of camel rearing, particularly in the Horn of Africa, with an associated increased risk of zoonotic disease emergence and spread. At the same time, integration of pastoralists into economic globalization is opening national and international markets for camel products, providing increased opportunity for introduction of potentially contaminated products into the human population.

Ongoing research in Nigeria to detect and characterize the viruses present in camel populations and map the complex camel trade network was presented. Comprehensive data collection at the dromedary-human interface, including serological, virological, genomic, socio-economic and anthropological data, is crucial for understanding risks associated with camel husbandry and trade.

Saudi Arabia presented on mass gathering events including the Hajj, although no human cases of MERS have been linked to such events. MERS-CoV remains a threat that requires continuous monitoring at large events. Targeted interventions, such as testing individual camels before they are allowed into an event and banning camel slaughter during gatherings, should be implemented to mitigate risks.

Other presenters reported on studies that detected MERS-CoV ribonucleic acid (RNA), but not infectious virus, in raw camel milk collected using traditional milking methods. Evidence for zoonotic transmission associated with camel urine or meat is currently lacking. Further targeted and carefully designed studies are needed to confirm alimentary zoonoses; or any role of camel products in the transmission of MERS-CoV to humans.

Plenary Session: Molecular Characterization of coronaviruses, focus on MERS-CoV and SARS-CoV-2: what has been learned

In this session, speakers were allotted five minutes each to convey their most critical messages regarding the molecular characterization of coronaviruses.

Speakers: Christian Drosten, Charité Berlin, Germany; Rachael Dempsey, University of Liverpool, United Kingdom of Great Britain and Northern Ireland; Stanley Perlman, University of Iowa, United States of America; Julian A. Hiscox, University of Liverpool, United Kingdom of Great Britain and Northern Ireland; Bart Haagmans, Erasmus MC, Netherlands (Kingdom of the); Ihab ElMasry, FAO HQ, Italy; Takele A. Tefera, National Veterinary Institute, Ethiopia (by video); Tracey Goldstein, University of California, United States of America; Jane Cunningham, WHO HQ

Summary

Functional comparison of MERS-coronavirus lineages. Phenotypic variations between Arabian and African viruses were presented. Lineage 5, which is now circulating in the Arabian Peninsula after having out-competed all previous lineages, demonstrates increased replicative

fitness, notably in cell lines capable of producing interferon. Lineage 5 exhibits a unique ability to suppress cytokine induction efficiently, therefore inhibiting immune response.

Genotype to phenotype consequences in MERS-CoV. The diverse genome of coronaviruses has been explored through research with pseudoviruses, non-infectious virus replicons and recombinant viruses to study genetic determinants of viral entry and replication. MERS-CoV isolated from clinical samples shows variability across the genome, but more research is needed to understand how this may affect viral load, patient outcomes and transmissibility.

MERS-CoV biology and ORF8b. Every coronavirus has proteins involved in immune evasion. One example is ORF8b, an accessory protein unique to betacoronaviruses, which is embedded in the N protein. It has been shown that the deletion of MERS-CoV ORF8b results in increased virulence. There is a clear need to further explore the fundamental biology of MERS-CoV.

Predicting SARS-CoV-2 evolution. The high rate of mutations in SARS-CoV-2 presents challenges in planning countermeasures. Signals of future variants including Omicron were detected in early samples, underscoring the importance of proactive monitoring, reporting and risk assessment.

Potential for recombination in MERS-CoV and SARS-CoV-2. An outbreak of recombinant coronavirus in felines in Cyprus involved marked phenotypic changes, such as possibility of spread in the enteric tract and caused thousands of fatalities in cats. To understand if recombination is possible for SARS-CoV-2 and MERS-CoV, susceptibility and potential for transmission need to be explored. However, the chance for recombination appears to be lower than it is for feline/canine coronaviruses viruses. To date, there has been no evidence of MERS-CoV and SARS-CoV-2 recombination, but this possibility represents a risk and requires further study.

Results from FAO field surveys on MERS-CoV and SARS-CoV-2 in camels in Oman. Camels are known to be susceptible to different coronaviruses including MERS-CoV, which circulates at high levels. A study in Oman (2022) collecting serological evidence of SARS-CoV-2 infection found positivity in one sheep, three goats and one camel. [*24*] For investigation of reverse zoonotic events, timely One Health collaboration is critical because the shedding window is limited.

Genetic diversity and molecular epidemiology of MERS-CoV in Ethiopian dromedaries. Camel-originated MERS-CoV in Ethiopia belongs to clade C2, but there is high genetic diversity and instability. This could lead to emergence of new strains. MERS-CoV is still adapting in this region and is in a state of constant evolution, which involves a risk for generation of more pathogenic strains that could affect humans. Findings highlight the need for constant vigilance and enhanced surveillance in dromedary camels and humans in Africa. Prevention of clade B introduction to Africa is critical given its known zoonotic potential and high case fatality rate.

Evolutionary history of ACE-2 usage within the coronavirus subgenus Sarbecovirus. Bats are the evolutionary hosts of many coronaviruses, including the sarbecoviruses, to which SARS-CoV-1 and SARS-CoV-2 belong. The ACE-2 receptor is being used by SARS-CoV-2 for cellular entry, but this is not a universal trait of sarbecoviruses and may have been acquired through recombination. For coronaviruses to recombine, they must first have the opportunity to do so by sharing geographic ranges and host species. The high diversity and overlap of bat species in Asia and parts of Africa indicate the need for increased surveillance in bats, camels and humans in these areas.

WHO initiatives supporting genomic sequencing. WHO published a 10-year genomic surveillance strategy in 2022 [*25*] and is promoting the timely sharing of biological materials through the BioHub, which offers a reliable, safe and transparent mechanism for WHO Member States to voluntarily share novel biological materials, without replacing or competing with existing systems. It was

recommended that biological materials with epidemic or pandemic potential be shared through laboratories designated as WHO BioHub Facilities.

Poster session: Improving surveillance, early detection and warning at the animal-human-environment interface

This session included posters from 16 institutions and focused on the need for sustained multi-disciplinary surveillance of MERS-CoV and other coronaviruses at the animal-human interface; and environmental impact, such as the role of climate change, in the epidemiology of MERS. After having time to view the posters, participants met in plenary to share their impressions.

The posters provided an overview of the work in MERS-CoV-endemic countries that have conducted good scientific work and utilized a One Health approach, especially for seroprevalence studies. Yet, routine animal surveillance for MERS-CoV is limited and is not being implemented within existing animal health programs.

Participants discussed the question of why human cases have not been reported in African countries despite the high dromedary populations with evidence of MERS-CoV circulation. They also noted variability in prevalence rates in the human population seroprevalence studies. Some participants stressed the need for studies at the epizonal or camel value chain level for better understanding of best and risky practices and risk communication to reduce spillover to humans.

Participants noted the importance of neutralization tests being used for confirmatory testing in serological surveillance for both humans and camels and that such studies should be complemented with molecular surveillance. Moreover, it was observed that characterization of T cell responses in humans is critical and should be given more attention. A recent study found that MERS-CoV specific T cell responses may be detectable in infected sero-negative individuals.[11] Participants expressed the need for continued refinement of surveillance protocols based on latest research findings and availability of resources to implement these refined tools.

Plenary Session: Improving surveillance, early detection and warning at the animal-human-environment interface

Parallel session A: MERS-CoV in humans

Surveillance and diagnosis in at risk countries: focus on MERS-CoV

Speakers: Abdullah Assiri, Ministry of Health Saudi Arabia; Hannah Kirking, US Centers for Disease Control and Prevention, United States of America; Nam-Hyuk Cho, Seoul National University, Republic of Korea; Christian Drosten on behalf of Marcel Müller, Charité Berlin, Germany; Ahmad Al Barrag, Public Health Authority, Saudi Arabia

Summary

The COVID-19 pandemic has influenced the way surveillance for MERS-CoV is conducted internationally. In Saudi Arabia, MERS-CoV has been included into sentinel surveillance mechanisms since early 2023, but this pathogen is only tested for in the case of a negative test for influenza and SARS-CoV-2. In the United States of America (USA), revisions by the Centers for Disease Control and Prevention (CDC) to the definition of a person under investigation (PUI) means that testing for MERS-CoV is less likely than it was pre-pandemic, but this definition now accounts for risk of exposure to dromedaries in Africa, based on studies demonstrating this risk. Communities must ensure that all cases of MERS-CoV are identified promptly, which will require careful sensitive, cost-effective and sustainable surveillance systems. The question as to whether the MERS case definition should be reviewed was raised (this was last updated in Saudi Arabia in 2018). [*26*]

A study showed that antibodies to MERS-CoV peaked at two years after infection and stabilized again at four years post-infection in a Republic of Korea cohort. [*27, 28*] There is some evidence of cross-protection between MERS-CoV and SARS-CoV-2, but much further research is required on this complex topic. [*27*] Use of T cells to detect MERS-CoV cellular immune response has been validated in multiple studies (see above).

Preventing infections in humans – advances in community protection and safe clinical care

Speakers: Vincent Munster, National Institutes of Health (NIH), United States of America; Majid Al Shamrani, Ministry of National Guard Health Affairs, Saudi Arabia; Dhouha Hamdani, Ministry of Health Qatar; Abdulrahman Fahad Alrezaihi, University of Liverpool, United Kingdom of Great Britain and Northern Ireland; Waleed Aljabr, King Fahad Medical City, Saudi Arabia

Summary

While SARS-CoV was not considered to have high human-to-human transmissibility, SARS-CoV-2 is highly transmissible. MERS-CoV results in limited human-to-human transmission despite continuous spillover into the human population but has a high propensity for nosocomial transmission in health care settings when aerosol-generating procedures are performed.

Tropism defines coronavirus' capacity for transmission via the upper or lower respiratory tract. While SARS-CoV-2 is highly transmissible due to its ability to infect the upper respiratory tract, MERS-CoV settles in the lower respiratory tract in humans, making it less likely to spread easily when an infected individual talks or expels droplets from the mouth. By contrast, dromedary camels shed MERS CoV extensively from the upper respiratory tract, with high viral loads.

Asymptomatic transmission of MERS-CoV can occur in healthy individuals, including children, mainly in family or close contact settings. Once the infection is detected, affected individuals should isolate until they receive a negative test.

In the 2014 outbreak in Jeddah, Saudi Arabia, nosocomial infections were recognized as a major risk of transmission in health facilities owing to a combination of contact, droplet and airborne transmission. Infection prevention and control has been recognized as a vital field in preventing and controlling MERS.

Updates on clinical care and therapeutics for coronaviruses

Speakers: Yaseen Arabi, King Abdulaziz Medical City, National Guard Health Affairs, Saudi Arabia (by video); Jamie Rylance, WHO HQ, Switzerland; Peter Horby, International Severe Acute Respiratory and emerging Infection Consortium (ISARIC) Global Support Centre, United Kingdom of Great Britain and Northern Ireland

Summary

As with other domains, the important work conducted on MERS therapeutics prior to the COVID pandemic was highly influential in framing the basis for the COVID-19 therapeutics. Because they are both respiratory coronaviruses, there are similarities in the management of COVID-19 and that for MERS-CoV, especially for acute hypoxemia, respiratory failure and organ failure due to thrombosis. However, due to its affinity for the lower respiratory tract, MERS-CoV is prone to causing more severe disease, often with fatal outcome.

Many questions remain about the most successful interventions for the treatment of MERS. Attempts with convalescent plasma have been disappointing, as has the use of corticosteroids. Interferon has been found to help patients with a low inflammatory response who are treated early in the course of the illness. The need to build capacity and infrastructure for medical oxygen in countries affected by MERS was emphasized.

Advancing our understanding in cross-reactivity/cross-protections between MERS-CoV and other coronaviruses

Speakers: Sarah Batawi, Oxford University, United Kingdom of Great Britain and Northern Ireland; Simon Funnell, UK Health Security Agency (UKHSA), United Kingdom of Great Britain and Northern Ireland; Ziad Memish, King Saud Medical City, Ministry of Health Saudi Arabia

Summary

There is some evidence of cross-protection between MERS-CoV and SARS-CoV-2. The identification of MERS correlates of protection will facilitate effective vaccine development and monoclonal antibody therapy, and an understanding of the impact of cross-reactivity between coronaviruses will inform future MERS immunization strategies. To advance this understanding, the development of a wider range of MERS-specific assays, improved access to clinical specimens and international collaboration between research groups are needed. Furthermore, it would be useful to implement system serology alongside traditional testing after vaccination in humans.

It is important to be prepared for the possibility of human-adapted MERS-CoV variants with the potential for sustained human-to-human spread. Exploring potential cross-reactive immunity can guide ongoing global efforts to develop effective vaccines. However, many questions remain unanswered and one of the most important is: does cross-reactivity lead to cross protection?

Parallel session B: MERS-CoV infection in animals and its impact

Prevention and control in dromedary camels: One Health impact

Speakers: Isaac Ngere, Washington State University, United States of America; Gaddafi Mohhamed Sani, Ministry of Animal Health, Husbandry and Fisheries, Nigeria; George Chege Gitao, University of Nairobi, Kenya; Maged Hemida, Long Island University, United States of America; Asisa Volz, Tieraerztliche Hochschule Hannover, Germany; Amy Dighe, Johns Hopkins Bloomberg School of Public Health, United States of America

Summary

The age-sex structure of camel herds, camel husbandry practices, virus shedding and high rates of reinfection in dromedary camels contribute to the risk of MERS circulation in camel herds. Awareness of and vigilance concerning these risk factors is key to prevention and control of MERS-CoV in these animals. [29]

In naturally infected camels in Saudi Arabia, MERS-CoV causes pathological changes in the upper respiratory tract and is associated with acute interstitial pneumonia. This finding underscores the need for further investigations into the pathogenesis of the clade C virus that is circulating in camel populations in African countries. [*30*]

Ensuring camel products are safe for consumption implies a holistic approach that includes proper hygiene, regulation compliance and ongoing surveillance. International animal control posts at borders to prevent cross-border spread, alongside surveillance strategies in slaughterhouses and camel markets, have been successful strategies with One Health impact. Updates on MVA-MERS-S vaccine development for dromedary camels and models assessing MERS-CoV transmission and the potential impact of animal vaccination were discussed.

Detection and diagnosis in animals

Speakers: Abdelmalik Khalafallah, Abu Dhabi Agriculture and Food Safety Authority, United Arab Emirates; Ulli Wernery, Central Veterinary Research Laboratory Dubai, United Arab Emirates; Ihab El Masry, FAO HQ, Italy; Francesco Bonfante, Istituto Zooprofilattico Sperimentale delle Venezie, Italy

Summary

Because MERS-CoV is widely circulating in some populations of dromedary camels, resulting in high antibody prevalence, serological evidence does not help to determine active infection or help with case confirmation. WOAH has published a case definition for reporting confirmed MERS-CoV infection in dromedaries based on isolation of the virus or identification of viral nucleic acid specific to the virus (**Chapter 16.2 of the Terrestrial Code***)*.

Viral RNA has been detected in conjunctival, oral and rectal swabs; saliva; milk and urine samples; semen; and lymphoid tissues of camels. RNA shedding has been detected through several non-respiratory routes, but the shedding level and the presence of infectious virus is not clear. Shedding amounts and routes could be affected by the exposure dose, interval between camel infection and sampling, virus clade and host intrinsic factors, as well as through several non-respiratory routes, sometimes without corresponding nasal shedding.

Calves are initially protected by maternal antibodies but become susceptible to MERS-CoV between 4 to 6 months of age. The virus is present in the nose of young dromedaries up to adolescent age (8 to 10 months). Over 95% of adult dromedaries over 2 to 4 years of age possess MERS-CoV antibodies for at least 10 years or during their entire lifetimes.

WOAH has published the international standards for diagnostic testing of dromedaries for MERS (Chapter 3.5.2 of the Terrestrial Manual). However, critical challenges faced by veterinary diagnostic laboratories include the validation of diagnostic techniques for animal MERS-CoV testing, lack of standard materials and quality assurance samples, clear understanding of viral kinetics in animals and lack of validated diagnostic kits.

Community engagement and prevention of spillover of zoonotic coronaviruses

Speakers: Suzanne Kerba, WHO HQ, Switzerland; Karen Saylor, Labyrinth, United States of America; Javier Guitian, Royal Veterinary College (RVC), United Kingdom of Great Britain and Northern Ireland

Summary

This session highlighted the need for more effective risk communications and community engagement (RCCE) strategies with different audiences. For example, owners of professional racing camels and Bedouins who rely on camels for food, drink and transportation both share an interest in camels, but they have profoundly different priorities and circumstances, which must be considered in developing effective interventions.

With vaccination being considered as a future broad strategy, factors influencing vaccine acceptance need to be considered. They often include the perception of safety, side effects, trust in health authorities and access to reliable and timely information. [*31*] For camel owners, these factors may be influenced by their perceptions of risk of MERS-CoV along with their experiences with and beliefs about vaccines in general. One panellist noted that the effectiveness of COVID-19 vaccines has led some previously resistant communities to now consider MERS-CoV vaccination for their animals.

More social-behavioural research is needed to better understand risk perception, address uncertainty and build trust within communities. Capacity building was cited as a critical need to build sustainable relationships, engage community influencers and empower communities.

Plenary session: Advancing vaccine development for beta-coronaviruses and readiness for implementation of vaccination

Speakers: Christopher Da Costa, Coalition for Epidemic Preparedness Innovations (CEPI), United States of America (by video); Jonathan L. Heeney, University of Cambridge, United Kingdom of Great Britain and Northern Ireland; Paul Duprex, University of Pittsburgh, United States of America; Francesco Bonfante, Istituto Zooprofilattico Sperimentale delle Venezie, Italy

Summary

The Coalition for Epidemic Preparedness Innovations (CEPI) outlined their vaccine development programme and aim to advance candidate vaccines through Phase 2 clinical trials with the goal of developing a stockpile of human vaccines to be used in the control of regional outbreaks. Two single immunogen and four broadly protective vaccine candidates are currently in development under the CEPI MERS portfolio. The sporadic nature of human MERS cases makes efficacy trials impossible. Preclinical data from animal models are consequently keyto licensing.

Efforts are ongoing to develop pan-Sarbeco/Merbeco vaccines. Coronaviruses are complex, but the genetic diversity of betacoronaviruses can be overcome by combining different computationally designed antigens in vaccine formulation, ensuring breadth of protection. Successful SARS-CoV-2 animal models such as mice, hamsters, ferrets and African green monkeys have been developed.

SARS-CoV-2 variant-specific antisera are needed for serology-based predictions of vaccine efficacy but are not readily available in the human population due to repeat infections with different variants. They can, however, be derived from naïve animals raised under controlled conditions. Rabbits represent the closest human model in antigenic distance maps. Optimization of antigenic characterization for vaccine testing could be achieved through wide access to panels of reference animal sera.

Access to sequence information and isolates of currently circulating strains and variants for all the different viruses to be included is a prerequisite for broadly protective vaccine development. However, single immunogen vaccines are easier to test and license than broadly protective ones, and it may take another 4-5 years until a broadly protective vaccine will be available on the market, unless innovative solutions are found.

Plenary session: Discussion on readiness for implementation of vaccination

Panel participants: Stanley Perlman, University of Iowa, United States of America; Bart Haagmans, Erasmus MC, Netherlands (Kingdom of the); Simone Kardinahl, IDT Biologika, Germany; Dominick Laddy, Vaccitech US, United States of America; Naif Alharbi, Gulf CDC, Saudi Arabia

Summary

Vaccine researchers from academia and representatives of vaccine companies shared the status of their respective vaccine development plans. Only Phase I clinical trials have been completed for these vaccines to date. Phase II clinical trials are being planned in Saudi Arabia in 2025 for a Modified Vaccinia Virus Ankara (MVA) vaccine, which should be available for emergency use by 2028, and a replication-deficient chimpanzee adenoviral vector (ChAdOx1 MERS) vaccine.

While funding and technology will drive forward vaccine development, the public health burden or need will determine uptake in the field: which has not been studied for MERS. The disease is known to have high pathogenicity and represents a potential threat, but major outbreaks happened more than five years ago, and currently there are only sporadic human cases. Discussions are ongoing with regulatory authorities about the appropriate pathway for licensing MERS vaccines,

given the limited feasibility of conducting Phase III efficacy trials at this time.

Licensing a MERS vaccine may have to rely on results from Phase II trials and appropriate animal models. Requirements for such licensing under exceptional circumstances will include quantitative definitions of the threshold of immune response associated with protection, demonstrating in a pivotal clinical trial that immune response is induced in humans, and with a manufacturing process in place that is appropriate for commercialization. Approvals for vaccine use need to be discussed with the local authorities in MERS-affected countries in the Middle East and Northern Africa. Ideally the Phase II clinical trials should be conducted there. Benefit sharing and access to stockpiles could be provided as incentives for conducting these trials, and international collaboration is key.

Different scenarios for MERS-CoV vaccine use–either proactive vaccination of exposed populations like camel workers or reactive vaccination in response to an outbreak–should be studied in more detail. All the ongoing efforts in MERS-CoV vaccine development could be redirected quickly should a new coronavirus emerge as a pandemic threat, as was seen during the early days of the COVID-19 response. Barriers to uptake of vaccination in camels include reluctance to vaccinate these highly valuable animals in the absence of any disease signs. Public health value may not be enough to convince owners, but combining MERS-CoV vaccines with those for camel diseases like camel pox or brucellosis may be an entry point. Also, the camel population in countries can be very dynamic, and vaccination of camels near borders would need to be implemented, which still only covers part of the camel population in a country. Waning of immunity response was evidenced in camels, and they can be re-infected with the virus, suggesting that vaccination would require regular boosters. Waning of immunity in humans needs to be further investigated as well.

Plenary session: Research priorities

Advancing pathogen family R&D roadmaps and target product profiles, planned next steps and timelines

Speaker: Ana-Maria Henao-Restrepo, WHO HQ, Switzerland (by video)

Summary

The R&D Blueprint has gathered 200 experts who are reviewing evidence and will release a list of priority pathogens for research in 2024. The work involves grouping viruses and bacteria into families and studying selected pathogens within a given family to inform research and the design of medical countermeasures. The group will be developing research roadmaps for viral and bacterial families and ultimately develop broadly protective vaccines.

Breakout session to identify research priorities

In this session, meeting participants split into facilitated discussion groups to identify research gaps and priorities (see part I of this report for results).

The way forward

In the final session of the meeting, participants gathered in small groups to weigh in on the specific activities required to fill current gaps in MERS research and what they or their organization or institution could offer. This material is summarized in Annex 1. Enhanced global coordination by WHO and the other Quadripartite partner organizations (FAO, UNEP and WOAH) was highlighted as a key aspect for advancing the research agenda in a targeted and cost-effective way, strengthening international collaboration and preventing duplication of efforts.

5. Conclusion

Participants in this meeting noted that the intense focus on SARS-CoV-2 during the COVID-19 pandemic led to a lapse in attention to MERS-CoV as a current and possibly major future public health threat. Now is the time, they agreed, for an invigorated research agenda on MERS. Rapid scientific advances made during the pandemic in the prevention, diagnosis and treatment of diseases caused by coronaviruses and lessons learned during the COVID-19 pandemic have to be incorporated into the prevention and control of MERS.

Some of the critical research gaps remain the lack of a licensed vaccine for either humans or camels and licensed therapeutic for humans. Treatment of MERS cases remains non-specific and supportive. Because of the low incidence and sporadic nature of MERS in humans, efficacy trials are currently not feasible, making data from appropriate animal models the only path towards licensure. Additional research on the duration of antibody responses is crucial to inform vaccine development.

Participants agreed that increased geographic coverage and temporal continuity of surveillance is key to understanding the true zoonotic infection risk and burden of disease. Timely generation and sharing of sequence data and isolates is critical for risk assessment and research on targeted countermeasures; these have lapsed and need to be reinstalled. The significance of incorporating MERS-CoV into multi-pathogen rapid tests for enhanced routine surveillance was highlighted, as was the importance of providing low- and middle-income countries affected by MERS with access to these tests. Applicability and relevance of environmental surveillance should be explored as an additional, cost-effective surveillance component.

Given the global circulation of SARS-CoV-2, cross-protection or cross-reactivity with MERS-CoV (e.g. in serological assays) must be further investigated as it may have implications for infection severity, transmission risk, and the interpretation of serology results. ELISA is a frequently used serological method for MERS-CoV surveillance, and researchers should investigate how to differentiate between true positives, cross-reactivity with other coronaviruses in the post-COVID-19 era and other potential false positives. Improving the specificity of serological tests will enhance the accuracy of MERS-CoV surveillance data, allowing for more reliable epidemiological assessments.

To enhance targeted mitigation measures, there is a need for enhanced detection of asymptomatic or mild human cases and improved understanding of the role that they play in transmission, as well as the factors and role of shedding in camels at the animal-human interface. Additionally, for camels, more information on shedding routes, shedding intervals and the impact of immunity (whether natural or vaccine-induced) in modulating or eliminating shedding is needed.

The drivers and determinants of MERS-CoV transmission and spillover and the needs, perceptions and capacities of different at-risk

communities able to help prevent them must be identified. Factors affecting community acceptance and uptake of vaccines–once they are developed–also need to be explored. Social and behavioural science approaches will be critical for all these areas of investigation.

The Quadripartite partner organizations will capitalize on the heightened interest and momentum generated by this meeting and ramp up efforts to enhance global coordination for advancing the research agenda in an efficient, targeted and cost-effective way, striving to prevent duplication of efforts.

Participants

Around 240 participants from 51 countries attended the meeting. Invited stakeholders included representatives from ministries of health, ministries of agriculture and ministries of environment in affected and at-risk countries, MERS-CoV and zoonotic coronavirus subject matter experts and researchers, funding agencies, industrial partners and representatives from FAO, UNEP, WHO and WOAH at headquarters, regional and country levels. Speakers are identified in the agenda (Annex 2).

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Annex 1. Table listing research and implementation needs and offerings by participants to fill those needs

Table A1.1: Research and implementation needs and offerings by participants to fill those needs

Topics	Research and implementation needs	Offered by participants

Surveillance	• Framework for surveillance in non-endemic countries and definition criteria for testing (including rapid tests) of asymptomatic cases, along with triage tools
	• Integrated human/animal diseases surveillance
	  ▪ Targeted sentinel surveillance through expanded GISRIS
	  ▪ Establishment of sentinel sites for camel reporting
	  ▪ Surveillance evaluating tools to be applied to high-risk countries
	  ▪ Monitor the dynamics of MERS-CoV; know and assess the role of humans on MERS-CoV transmission
	  ▪ Include genomics as part of integrated surveillance system
	• Laboratory diagnostics support; capacity for:
	  ▪ Reagents for MERS surveillance in Africa
	  ▪ Support in establishment of neutralization assays
	  ▪ PCR test optimization
	  ▪ Protocols for serology
	  ▪ Standardised use of serology for surveillance testing
	• Funding to continue conducting surveillance in wildlife, support for longitudinal study follow up across all seasons
	  ▪ Cost benefit- analysis to justify surveillance cost for decision makers
	  ▪ Funding to understand surveillance across the Horn of Africa
	• Examples of robust community-based surveillance frameworks.
	• Sharing of best practices from different countries in relation to surveillance of MERS-CoV especially on strengthening early warning systems and/or event-based surveillance so that non-endemic countries will learn from them
	• Capacity building of molecular surveillance and camel sampling
	• Tracking animal value chain /environment and animal movement in camel trade
	• Understanding animal transmission (including bats) in transmission routes and in general better understanding of transmission routes (including environment aspect such as fomites)
		• Technical support/tools, education, awareness, surveillance tools, data analysis, spatio-temporal analytic skills, writing of results/papers
		  ▪ Support in training for serology and sampling/testing
		  ▪ Support in joint investigation guidelines specific for MERS/ SARS-CoV-2
		• Collaboration in establishing or strengthening community-based surveillance.
		• Financial support for continuous surveillance of MERS in Kenya
		• Collaboration to conduct studies, perform systematic review and meta-analysis to understand estimated pooled prevalence and associated risk factors in humans
		• Collaboration to engage in a field team, perform surveillance and implementation of activities in the field
		  ▪ Sites for studies (in Somalia) on humans and camels
		  ▪ Field surveillance networks established from previous activities.
		• Environmental sensor surveillance in markets/trade points
		• Wastewater surveillance- training and support with tools and protocols of sewage monitoring
		• Established network for continued environmental surveillance
		• Surveillance on the role of wild animals in MERS-CoV; bats, rodents and other wildlife species in camel keeping areas (in east Africa)

Topics	Research and implementation needs	Offered by participants
Diagnostics	• Low cost multiplex real-time PCR or antigen test for rapid detection of all known human coronavirus with high sensitivity and specificity	• R&D, production and testing equipment and protocols • Development of kits for comparison with new PCR test assays for validation purposes • Technical support in diagnostic study design • Technical assistance with diagnostic PCR (shipping , collection, analysis) and whole genome sequencing
Community engagement and risk	• Key messages for MERS and other coronaviruses during peacetime and during crisis • Raise awareness, capacity building, refresher trainings, trainings on diagnostics • Information on how to address vaccine implementation in animals and humans • Better assessment of communities needs and nature to address their engagement tactics; since every group must have specific engagement techniques (owners of camels or multiple animal species, people who raise camels for racing and competitions or raise camels for food/milk) • Technical support for qualitative studies identifying risk factors than can be targeted for interventions and their analysis • Anthropological expertise to gain community participation and engagement	• Coordination with the Global Health Security Advisors and their implementing partners in 11 countries in West Africa and sharing of materials and documents on RCCE • Resources to assist with community engagement and risk communication messaging and testing of messaging in pilot communities, local capacity building • Sharing country experiences of community engagement of prevention and control • Social media campaigns; experience with engaging influencers. • Share WHO/PRET coordinated community of practice • Quantitative and qualitative analyses support -including design and implementation of social network modelling (of camels and movement) and capacity building • Value chain studies – qualitative data collection and analyses (especially for socio-economics aspects, animal movement and vaccines) • Coordination of network of stakeholders
Sequencing/ genomics	• Genomic data sharing system with clinical and epidemiology data. Including available data to inform vaccine development • Funding to conduct the whole genome sequence of MERS-CoV • Participation in the WHO BioHub • Access to PCR positive samples, sequences • Collaboration on completion of ongoing and future studies on genetic diversity /dynamic in camels and human/handlers	• Capacity building, technology transfer and training for specialized assays and techniques including sequencing; and serological assays for MERS-CoV • Participation in CGENet (Clinical Genomic Epidemiology Network) • Access to back catalogue of SARS-COV variants and contemporary isolate stocks directly via the WHO BioHub • Field studies to collect samples from camels • Positive virus isolates from Africa • Assess the potential emergence of (virulent) variants and host-switching mechanism • Laboratory and sequencing capacity support along with protocols

Topics	Research and implementation needs	Offered by participants
Data Sharing	• Develop an open access database and integrated data analysis • Data sharing among countries to create a large data set and design of AI for further prediction • Diagnostics capacity for MERS including sequencing to support global diagnosis capacity • Genomic Sequencing data to be shared for betting mapping and data analysis • Real time sharing of unpublished work or ongoing work - data to be published through preprints and made public	• Sharing the data from CGENet platform to other networks. • Sharing of tools; protocols, methods, standardized data tools, frameworks, platforms (open access), data analysis • Molecular and epidemiology data from previous studies
Therapeutics	• Global collaboration on clinical studies • Assess antiviral and host directed therapies • Development of protocols – to be available once outbreaks begin • Affordable antivirals against coronaviruses • List of all therapeutics and prophylaxis against COV • Pan-COVD drug needs testing in animal models	• CEPI animal network in vitro and vivo studies • Capacity building in design of clinical studies, including production from laboratory to commercial scale monoclonal antibody production. • Assistance for drug developers to accelerate translational research • Assessing antiviral drug candidates for activity in vitro and animal models in BSL3
Vaccine development and implementation	• Need for field trials (for example, in West Africa) • Co-financing commercial viability analysis • Vaccination guidelines (low-risk, medium-risk, high-risk areas) • Support in conducting clinical trials • Need contemporary field data, government support, regulatory expeditions	• COVID-19 vaccine available via WHO C-TAP initiative with know-how and training that can be adapted to class 1 fusion glycoproteins & MERS, including the co-development, packaging and distribution technology • Clinical trials capacities and network of vaccine manufacturers (DCVMN) for distribution • Capacities for vaccine development, manufacturing/production • Preclinical assessment of vaccines in well documented /well controlled animal models • Community engagement with social media capacities – including social and behavioural participatory engagement • Implementation opportunities in the field (for example, in Jordan) and facilities with funding in endemic areas for camel vaccine trials (for example, in Kenya) • Access to assessment pathways and high containment vaccine assessment services

Topics	Research and implementation needs	Offered by participants
Further understanding of MERS in humans and animal-human interface	• Lessons learned from states that have experienced the disease in humans • Access to standardized protocols and reagents to develop T cell assays. This can also be achieved through the conduct of T cell studies in exposed populations with high prevalence of MERS (specific populations can be targeted such as the human handlers of camels)	• Mixed methods sampling techniques for humans and animals at risk • Cohort study of camels and camel handlers in Kenya • Research to understand the evolution of MERS-CoV within different clades • Characterization of T-cell response and memory T-cell response • Immunogenicity studies using different delivery systems • Animal challenge model studies on MERS using ABSL 2 facilities • Collaborative research opportunities with other institutes and experts to enhance the understanding and response to MERS • Assess the potential emergence of (virulent) variants and host-switching mechanisms

Annex 2. Meeting Agenda

Quadripartite Global Technical Meeting on MERS-CoV and Other Emerging Zoonotic Coronaviruses

Meeting: 27-29 November 2023 (In-person)

Location: Voco Hotel, Riyadh, Kingdom of Saudi Arabia

Host: FAO-UNEP-WHO-WOAH together with the Saudi Public Health Authority and Ministry of Health

Final Agenda

Day One – 27 November 2023			
TIME	**TOPICS**	**SPEAKERS**	**MODERATORS**
Plenary: Introduction and background			
9:00-9:50	**Welcome and Opening Remarks** • Abdullah Al Quizani, Chief Executive Officer, Public Health Authority, Saudi Arabia • Richard J. Brennan, Regional Emergency Director, WHO Regional Office for the Eastern Mediterranean • Maria Van Kerkhove, Director a.i., Department for Epidemic and Pandemic Preparedness and Prevention, WHO HQ • Ayman Omer, FAO Representative, Saudi Arabia • Aiman Etaluni, Saudi Environment Sustainability Programme, UNEP • Gounalan Pavade, WOAH HQ		**Moderator** Sophie von Dobschuetz, WHO HQ
9:50-10:05	Introduce agenda and timetable Administrative and housekeeping rules	Sophie von Dobschuetz, WHO HQ and Sally Berman, Facilitator	
10:05-10:30	**Setting the scene** Film: Advancing pandemic preparedness, readiness, response for coronaviruses: maintaining gains from MERS and COVID-19 Where we are - taking stock of achievements	Maria Van Kerkhove, WHO HQ Malik Peiris, University of Hong Kong, Hong Kong, China	
10:30-11:00 Coffee break and group photo			

Plenary session 1: Preparedness for coronaviruses using a One Health approach			
11:00-12:00	FAO and the One Health approach for zoonotic pathogens and the Quadripartite Joint Plan of Action on One Health	Baba Soumaré, FAO HQ, Italy	**Technical lead** Heba Mahrous, WHO Regional Office for the Eastern Mediterranean **Facilitator** Heba Mahrous, WHO Regional Office for the Eastern Mediterranean
	WHO collaborating center approach: Supporting coronavirus, including MERS-CoV, preparedness in the region	Emad Almohammadi, WHO MERS Collaborating Centre – Public Health Authority, Saudi Arabia	
	Gulf CDC's work on early detection, warning and notification of MERS-CoV and other zoonotic coronaviruses	Naif Alharbi, Gulf CDC, Saudi Arabia	
	Operationalization of the One Health approach in Egypt to tackle zoonotic coronaviruses	Amr Kandeel, Ministry of Health Egypt	
	One Health approach for assessing readiness and preparedness: COVID-19 DAR (During Action Review), Bangladesh	Salim Uzzaman, IEDCR, Bangladesh	
	WHO R&D Blueprint for Epidemics: strengthening global R&D for future epidemics and pandemics due to coronaviruses	Ana-Maria Henao-Restrepo, WHO HQ (Video)	
included in above	Q&A and moderated discussion		
Plenary Session 2: Science-policy interface discussion on preparedness and OH approach			
12:00-12:30	**Interactive debate - policy makers and scientists** How can we improve the quality of information flow at the science-policy interface – needs, challenges and solutions from scientists and policy makers	Dr. Abdullah Assiri, Ministry of Health Saudi Arabia (Video) Amr Kandeel, Ministry of Health Egypt Maria Van Kerkhove, WHO HQ Fatma Hussien Al Loghani, Ministry of Health and Prevention UAE Christian Drosten, Charité Berlin, Germany	**Technical lead** Lidewij Wiersma, FAO HQ **Facilitator** Sally Berman, Facilitator
	Q&A and moderated discussion		
12:30-13:30	***Lunch***		

Plenary Session 3: ***Conducting Risk Assessments for zoonotic coronaviruses to better to target prevention measures. Using strengthened national capacities from COVID-19 and MERS***			
13:30-14:10	FAO Qualitative Risk Assessment on MERS-CoV Clade B introduction through camel movements into Africa	Gisella Dias, FAO HQ	**Technical lead & facilitator :** Sophie von Dobschuetz, WHO HQ Supported by Ihab El Masry, FAO HQ
	The effect of climate change and economic globalization on camel farming systems worldwide	Bernard Faye, CAMENET	
	Enhancing early warning systems for MERS-CoV in the Nigeria-Sahel border: leveraging surveillance, risk assessments and One Health approaches	Oyelola Adegboye, Menzies School of Health Research, Australia	
	Risk Assessment for travel and mass gatherings in Saudi Arabia	Ahmad Mohamad Hakawi, Public Health Authority, Saudi Arabia	
	Risk of human infection from dromedary camel products	Isam Azhar, King Abdulaziz University, Saudi Arabia	
14:10-14:20	Q&A and moderated discussion		
14:20-14:30	Questions to the audience		
Plenary Session 4: ***Molecular Characterization of coronaviruses, focus on MERS-CoV and SARS-CoV-2: what has been learned***			
14:30-15:30	Functional comparison of MERS-coronavirus lineages reveals increased replicative fitness of the recombinant lineage 5	Christian Drosten, Charité Berlin, Germany	**Technical lead & facilitator:** Lidewij Wiersma, FAO HQ
	Genotype to phenotype consequences in MERS-CoV	Rachael Dempsey, University of Liverpool, UK	
	ORF8b ameliorates disease severity in MERS-1 CoV-infected mice	Stanley Perlman, University of Iowa, USA	
	Predicting the past and future evolutionary space of SARS-CoV-2	Julian A. Hiscox, University of Liverpool, UK	
	MERS-CoV recombination potential - including with other CoVs like SARS-CoV-2 - and implications on reservoir, transmission and severity	Bart Haagmans, Erasmus MC, Netherlands	
	Results from FAO field surveys on MERS-SARS-CoV-2 recombination	Ihab ElMasry, FAO HQ	
	Genetic diversity and molecular epidemiology of Middle East Respiratory Syndrome Coronavirus in dromedaries in Ethiopia, 2017–2020	Takele A. Tefera, National Veterinary Institute, Ethiopia; FAO and HKU (Video)	

	-The evolutionary history of ACE2 usage within the coronavirus subgenus Sarbecovirus	Tracey Goldstein, University of California, USA (Video)	
	- WHO initiatives to support genomic sequencing, sharing of biological materials and timely variant risk evaluation	Jane Cunningham, WHO HQ, Switzerland	
	Moderated discussion/Q&A / Questions to the audience		
Session 5: Poster session: Improving surveillance, early detection and warning at the animal-human-environment interface			
15:30-15:35	Introduction to poster session	Sally Berman, Facilitator	
15:35-15:40	Overview of published human and animal field surveys and outstanding surveillance gaps	Maya Hassan, WHO Regional Office for the Eastern Mediterranean, Egypt (Video)	
15:40-16:40	Coffee break and simultaneous poster session		
	(participants return to plenary room)		
Plenary Session 5 continued: ***Improving surveillance, early detection and warning at the animal-human-environment interface***			
16:40-17:25	Discussion / Q&A / Questions to the audience		**Technical lead & Facilitator** Hala Abou El Naja, WHO Regional Office for the Eastern Mediterranean and Sally Berman, Facilitator
Recap			
17:25-18:00	**Recap from day 1:** Advancing preparedness and early warning for zoonotic coronaviruses		Sally Berman, Facilitator
End of day 1 – free time with opportunity to visit poster session			
19:00	**Networking Dinner at Voco Hotel**		

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Day two – 28 November 2023			
TIME	**TOPICS**	**SPEAKERS**	**MODERATOR**
Plenary: Introduction			
9:00-9:10	Introducing agenda topics	Sally Berman, Facilitator	
Parallel Session A:			
6. Surveillance and diagnosis in humans in at risk countries: focus on MERS-CoV			
9:10-9:35	Updates to the Saudi MERS human case definition/testing diagnosis in the context of SARS-CoV-2 circulation	Abdullah Assiri, Ministry of Health Saudi Arabia	**Technical lead** Ruth McCabe, WHO HQ **Facilitator** Amal Barakat, WHO Regional Office for the Eastern Mediterranean
	US CDC risk assessment and Person Under Investigation (PUI) Update	Hannah Kirking, US CDC, USA	
	Seven-year follow-up study on antibody responses against zoonotic coronaviruses in Korean MERS cohort	Nam-Hyuk Cho, Seoul National University, Republic of Korea	
	Humoral and T cell responses upon MERS-CoV exposure	Christian Drosten on behalf of Marcel Müller, Charité Berlin, Germany	
	Progress on integrating MERS into multi-pathogen PCR, serology and genomic testing and surveillance	Ahmad Al Barrag, Public Health Authority, Saudi Arabia	
9:35-9:50	Moderated discussion /Q&A / Questions to the audience		
7. Preventing infections in humans – Advances in community protection and safe clinical care			
9:50-10:40	Understanding mechanisms of MERS-CoV exposure and transmission	Vincent Munster, NIH, USA	**Technical lead**: Alice Simniceanu, WHO HQ **Facilitator:** Dr Sami Al Mudarra, Gulf CDC
	Role of asymptomatic cases in the spread of MERS-CoV in community and health-care settings	Majid Al Shamrani, Ministry of National Guard Health Affairs Saudi Arabia	

	Country update on MERS/IPC from Qatar	Dhouha Hamdani, Lead, National Program for IPC, Ministry of Health Qatar	
	Investigating the relationship between the upper respiratory microbiome and disease severity patients with COVID-19 or MERS	Abdulrahman Fahad Alrezaihi, University of Liverpool, UK	
	- Amplicon and Metagenomic Analysis of Middle East Respiratory Syndrome (MERS) Coronavirus and the Microbiome in Patients with Severe MERS	Waleed Aljabr, King Fahad Medical City, Saudi Arabia	
10:40-10:50	Discussion /Q&A / Questions to the audience		
10:50-11:10	***Coffee break***		
8. Updates in clinical care and therapeutics for coronaviruses			
11:10-11:50	Clinical practice guidelines, optimized supportive care: lessons learned from COVID-19 and MERS	Yaseen Arabi, King Abdulaziz Medical City, National Guard Health Affairs, Saudi Arabia (Video)	**Technical lead** Alice Simniceanu, WHO HQ
	Clinical data platform: what is role of clinical surveillance?	Jamie Rylance, WHO	
	Clinical Characterisation Protocols (CCP): what's new with V3.0	Peter Horby, ISARIC Global Support Centre	Facilitator Jamie Rylance, WHO HQ
11:50-12:10	Discussion /Q&A / Questions to the audience		
9. Advancing our understanding of cross-reactive immunity in humans			
12:10-12:40	Exploring System Serology in the Context of Coronaviruses.	Sarah Batawi, Oxford University, UK	**Technical lead** Hala Abou El Naja, WHO Regional Office for the Eastern Mediterranean **Facilitator** Haleema Alserehi, Ministry of Health Saudi Arabia
	Assessment of the virulence of coronaviruses and the cross reactivity of immunity induced by infection and vaccination	- Simon Funnell, UKHSA, UK	
	Cross-protective immunity between MERS-CoV and SARS-CoV-2	Ziad Memish, King Saud Medical City, Ministry of Health, Saudi Arabia	
12:40-13:00	Discussion /Q&A / Questions to the audience		
Participants to return to plenary for second half of the day			

Parallel Session B:			
10. Prevention and control in dromedary camels: One Health impact			
9:10-10:10	Understanding the dynamics of MERS-CoV infection in dromedary camels and virus spillover to humans in Northern Kenya: Implications for Prevention and Control	Isaac Ngere, Washington State University	**Technical lead** Gisella Dias, FAO HQ **Facilitator** Ihab El Masry, FAO HQ
	Seroprevalence of the Middle East Respiratory Syndrome Coronavirus Antibodies in Camels from Two International Animal Control-posts, Kebbi State, Nigeria	Gaddafi Mohhamed Sani, Ministry of Animal Health, Husbandry and Fisheries, Nigeria	
	The Camel milk value chain in Kenya and Somalia: Opportunities and challenges	George Chege Gitao, University of Nairobi, Kenya	
	Moderated discussion		
	Role of immunity in camels in acquiring infection and shedding virus (title TBC)	Maged Hemida, Long Island University, USA	
	Prevention and control in animals including vaccines/ vaccination update	Asisa Volz, Tieraerztliche Hochschule Hannover, Germany	
	Modelling transmission of MERS-CoV in dromedary camels and the potential impact of animal vaccination on incidence in dromedaries	Amy Dighe, Johns Hopkins Bloomberg School of Public Health, USA	
	Moderated discussion Q&A / Questions to the audience		
11. Detection and diagnosis in animals			
10:10-10:50	MERS case definition in camels, requirements for reporting of positive findings in camels, diagnostic results	Abdelmalik Khalafallah, Abu Dhabi Agriculture and Food Safety Authority, UAE	**Technical lead** Gounalan Pavade, WOAH HQ **Facilitator** Bernard Faye, CAMENET
	MERS-CoV infection and detection in dromedaries – CVRL Dubai experience	- Dr Ulli Wernery, Central Veterinary Research Laboratory Dubai, UAE	
	MERS-CoV shedding from camels – highlighting the non-respiratory routes	Ihab El Masry, FAO HQ	
	Standardizing SARS-CoV-2 serological assays in animals	Francesco Bonfante, Istituto Zooprofilattico Sperimentale delle Venezie, Italy	
10:50-11:00	Discussion /Q&A / Questions to the audience		
11:00-11:40	***Coffee break***		

12. Community engagement and spillover prevention of zoonotic coronaviruses			
11:40-12:30	**Panel discussion:** The Art of Camel Racing: Risk Perceptions and Challenges in Community Engagement Responding to the challenge of MERS-CoV: Development and testing of interventions to reduce risk among Bedouin populations in Southern Jordan.	Suzanne Kerba, WHO HQ Karen Saylor, Labyrinth, USA Javier Guitian, Royal Veterinary College, UK	**Technical lead** Suzanne Kerba, WHO HQ **Facilitator** Suzanne Kerba, WHO HQ
12:30-12:40	Discussion /Q&A / Questions to the audience		
13:00-14:00	***Lunch***		
13. Plenary Session Debrief			
14:00-14:40	Debrief from parallel sessions A & B		**Facilitator** Sally Berman
14. Advancing vaccine development for beta-coronaviruses			
14:40-15:00	Overview of CEPI's MERS-CoV vaccine portfolio	Christopher Da Costa, CEPI, USA (Video)	**Technical lead** Sophie von Dobschuetz, WHO HQ **Facilitator** Cassandra Jones, US CDC, USA
	Prediction of protection of MERS vaccine candidates in animals and people: Towards pan-Sarbeco/ Merbeco vaccines	Jonathan L Heeney, University of Cambridge, UK	
	SARS-CoV-2 and MERS-CoV animal models	Paul Duprex, University of Pittsburgh, USA	
	Animal models for antigenic distance mapping for SARS-CoV-2	Francesco Bonfante, Istituto Zooprofilattico Sperimentale delle Venezie, Italy	
15:00-15:10	Moderated discussion, Q&A		
15. Discussion on readiness for implementation of vaccination			
15:10-15:40	**Panel discussion:** Where are we with development and approval of MERS-CoV vaccine candidates? How would we make MERS vaccines available during an outbreak / outside of an outbreak scenario? Learning from past outbreaks • Stanley Perlman, University of Iowa, USA • Bart Haagmans, Erasmus MC, Netherlands • Simone Kardinahl, IDT Biologika, Germany • Dominick Laddy, Vaccitech US, USA • Naif Alharbi, Gulf CDC, Saudi Arabia		**Technical lead** Sophie von Dobschuetz, WHO HQ **Facilitator** Cassandra Jones, US CDC, USA
15:40-16:10	***Coffee break***		
16. What is needed in research – addressing unknowns			
16:10 –17:10	"What is needed" Interactive session of research areas		Sally Berman, Facilitator
17:10-17:20	Discuss the next day's agenda		Sally Berman, Facilitator
End of day 2			

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Day Three – 29 November 2023

TIME	TOPICS	SPEAKERS
09:00-09:10	Introducing agenda topics	Sally Berman, Facilitator
17. Research Priorities and updating existing priority pathogen roadmaps: moving to pathogen families		
09:10-09:20	Advancing pathogen family R&D roadmaps and target product profiles, planned next steps and timelines	Ana-Maria Henao-Restrepo, WHO HQ (Video)
09:20-09:30	Summarizing outcomes from the past 2 meeting days – introduction to the group work	Sophie von Dobschuetz, WHO HQ
18. What is needed to move forward with filling the knowledge gaps and who can do what		
09:30-11:00	Group work on topics discussed on days 1 and 2; what are next steps and who will tackle what	Sally Berman, Facilitator
11:00-11:30	*Plenary debrief*	Sally Berman, Facilitator
Closing		
11:30-12:15	Closing and way forward • Baba Soumare, Food and Agriculture Organization of the United Nations (FAO) • Gounalan Pavade, WOAH HQ • Amal Barakat, WHO Regional Office for the Eastern Mediterranean • Emad Almohammadi, Public Health Authority (PHA) Saudi Arabia	
End of meeting		
12:15-13:15	***Lunch***	

Global Respiratory Threats Unit
Epidemic and Pandemic Threat Management Department

World Health Organization
20 avenue Appia
1211 Geneva 27
Switzerland

Email: MERSHQ@who.int
Website: https://www.who.int/health-topics/middle-east-respiratory-syndrome-coronavirus-mers

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