Infection control in the intensive care unit: expert consensus statements for SARS-CoV-2 using a Delphi method

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During the current COVID-19 pandemic, health-care workers and uninfected patients in intensive care units (ICUs) are at risk of being infected with SARS-CoV-2 as a result of transmission from infected patients and health-care workers. In the absence of high-quality evidence on the transmission of SARS-CoV-2, clinical practice of infection control and prevention in ICUs varies widely. Using a Delphi process, international experts in intensive care, infectious diseases, and infection control developed consensus statements on infection control for SARS-CoV-2 in an ICU. Consensus was achieved for 31 (94%) of 33 statements, from which 25 clinical practice statements were issued. These statements include guidance on ICU design and engineering, health-care worker safety, visiting policy, personal protective equipment, patients and procedures, disinfection, and sterilisation. Consensus was not reached on optimal return to work criteria for health-care workers who were infected with SARS-CoV-2 or the acceptable disinfection strategy for heat-sensitive instruments used for airway management of patients with SARS-CoV-2 infection. Well designed studies are needed to assess the effects of these practice statements and address the remaining uncertainties.

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Introduction

The COVID-19 pandemic continues to cause substantial strain on health-care resources worldwide. As the primary mode of transmission of SARS-CoV-2 was initially considered to be droplets, the main focus of infection control was towards preventing direct human-to-human transmission with social distancing, wearing face masks, hand washing, and disinfection of virus-contaminated surfaces.[1] However, emerging evidence suggested an important role for airborne transmission, especially in indoor environments, such as health-care establishments.[2–4] Major public health agencies have accepted the evidence of airborne spread,[5,6] and the urgent need to minimise spread to both health-care workers and uninfected patients has resulted in many structural and organisational changes in intensive care units (ICUs) in the absence of strong evidence.

Health-care workers, their households, and hospitalised patients are at a higher risk of being infected with SARS-CoV-2 compared with the general community.[7–9] This risk is attributed to close contact with patients, especially due to coughing and using aerosol-generating procedures (AGPs).[8,10] According to WHO estimates, health-care workers contributed to 2–35% of all reported cases with COVID-19 depending on the country's resources and reporting systems.[11] Patients with COVID-19 treated in ICUs are unique in that they have a greater severity and duration of illness, their treatment involves AGPs, and they might receive immunosuppressive agents, and are therefore at a higher risk of acquiring healthcare-associated infections compared with non-ICU patients.[12–16] An increase in healthcare-associated infections has also been noted in patients with COVID-19 during the pandemic. This increase most likely has several causes, including fear of self-contamination and the unprecedented strain on health-care resources resulting in suboptimal infection control practices.[12]

Public health agencies have issued general recommendations for infection control of SARS-CoV-2, including prevention of nosocomial spread and health-care worker safety.[15–17] Most recommendations are based on commonly used measures to prevent droplet and airborne infections, and on experience from previous coronavirus outbreaks, caused by SARS-CoV and MERS-CoV. However, absence of evidence-based recommendations for infection control for patients with

Key messages

- Multidisciplinary experts, including those from low-income and middle-income countries, reached broad consensus on infection control measures for SARS-CoV-2 in intensive care units
- Patients with COVID-19 should be separated from other patients
- Health-care workers should be vaccinated against COVID-19 and wear full personal protective equipment, including an N95 mask and face shield for routine care of patients with COVID-19
- Routine testing of health-care workers for SARS-CoV-2 infection is not recommended
- Hand hygiene, infection control surveillance, antimicrobial stewardship, environmental disinfection, and waste separation should be carried out as for patients without COVID-19
- Ideal practice might be amended if facilities or equipment are unavailable

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COVID-19 in ICUs has led to modifications in standard infection control practices. Given the dearth of evidence, we aimed to reach a consensus on infection control in the ICU for SARS-CoV-2, using a Delphi process.

Methods

Delphi process

A steering committee was formed consisting of eight international physicians, all of whom were involved in the management of patients with COVID-19 and had expertise in infectious diseases, microbiology, infection control, or intensive care medicine. A Delphi process was initiated to generate consensus on infection control practices for SARS-CoV-2 in ICUs.[18–20] The study was registered with ClinicalTrials.gov (NCT04665960).

The steering committee members did not participate in the Delphi surveys themselves but recruited and convened an international group of clinicians actively involved in the management of patients with COVD-19 with expertise in infectious disease, infection control, intensive care medicine, respiratory failure, and public health. Email invitations were sent to 40 global experts to participate. Upon acceptance, experts were included in the Delphi process to generate consensus but did not know the identity of the other participants. Participation was voluntary and consent was implied if the participant responded to the survey.

The steering committee systematically searched PubMed, MEDLINE, Embase, and used search engines (Google and Google Scholar) for original articles on infection control of SARS-CoV-2 in ICUs between Jan 1, 2020, and March 28, 2021. The search string used for the literature search is provided in the appendix (pp 2–4). A list of interventions was prepared for the absence of clear evidence. These interventions were presented as clinical statements to the experts in the form of a survey questionnaire using Google Forms. The survey questionnaire had five sections: ICU design and engineering, health-care workers and visitors, personal protective equipment (PPE), patients and procedures, and disinfection and sterilisation. The questions included were either in a seven-point Likert scale or multiple-choice question format. The first round of the survey had open-ended questions to receive feedback from the experts. The experts subsequently responded to several rounds of survey questionnaires done with an iterative approach using the Delphi method to prioritise topics for inclusion.

Consensus and stability

Consensus was defined as an agreement (scores 5–7) or disagreement (scores 1–3) by more than 70% of the experts in the Likert-scale statements.[18–20] Medians (IQR) were used to express the central tendency and dispersion of responses for the Likert-scale questions. For the multiple-choice questions, consensus was defined as more than 80% agreement for a particular choice. Stability of the responses was checked with non-parametric chi-squared (χ^2) tests from round two onwards.[18,19] A p value of less than 0·05 was considered a significant variation or unstable. A statement was continued in the questionnaire round until stability of the responses was reached. Consensus statements were considered as those that generated consensus and stability.

Clinical practice statements

Clinical practice statements were issued by the steering committee from the statements that generated consensus. Based on results of the Delphi surveys, research priorities for infection control of SARS-CoV-2 in ICUs were identified to address the remaining uncertainties. The final results of the survey, clinical practice statements, list of priorities for research, and the manuscript were circulated among the experts for approval before submission for publication.

Results

35 (88%) of the 40 experts invited from 22 countries across six continents participated and 34 (97%) of 35 completed all rounds of the Delphi process (appendix p 5). The median age of the experts was 56 years (IQR 12); five (14%) of 35 participants were women. 32 (91·4%) of 35 participants were affiliated with university hospitals. All 35 experts who participated in the survey had an infection control programme in their hospitals, with 30 (86%) having an antimicrobial stewardship policy. A COVID-19 management protocol was followed in 94% of hospitals where the experts worked.

Four survey questionnaire rounds were conducted between March 29, and April 20, 2021. Details of the Delphi rounds and consensus process are provided in the appendix (p 6). The results of the 33 survey questionnaire statements are shown in the table. At the end of the Delphi process, 31 (94%) statements reached consensus and stability, from which 25 clinical practice statements were drafted (figure). Reports of the first four survey rounds are provided in the appendix (pp 7–148). Research priorities for infection control of SARS-CoV-2 in ICUs are listed in the panel.

Clinical practice statements

The Delphi surveys generated consensus from experts for 31 statements on infection control of SARS-CoV-2 in ICUs addressing crucial knowledge gaps. From these statements, 25 clinical practice statements were drafted, including guidance on placement of patients with COVID-19, ICU design and engineering, health-care workers, visiting policy, PPE, hand hygiene, discontinuation of transmission-based precautions, AGPs, infection control surveillance, antimicrobial stewardship, and waste management, cleaning, and disinfection (figure). Until evidence is generated on the best means for prevention of transmission of infection while maintaining patient and health-care worker safety, the clinical

	Agree	Neutral	Disagree	Median (IQR)	χ^2 p value
Design and engineering					
Patients with suspected or confirmed COVID-19 in ICUs should be separated from patients without COVID-19 to reduce the cross transmission of SARS-CoV-2	91·0%	3·0%	6·0%	7 (0)	0·14
AGPs for patients with COVID-19 should preferably be performed in AIIRs	97·1%	2·9%	0%	7 (0)	0·13
Telemedicine ICU or remote monitoring can be used for patients with COVID-19 to reduce the cross-transmission risk to health-care workers by limiting avoidable patient contact	100%	0%	0%	6 (0)	1·0
Which of the following patient placement method in ICU is acceptable for patients with COVID-19?	..	..	..	..	0·58
Only in AIIRs	35·3%	..	..	..	..
AIIRs only for AGPs, otherwise in a single room with a closed door	44·1%	..	..	..	..
Preferably in AIIRs, otherwise grouping patients with standard distance	82·4%	..	..	..	..
No separation of patients with COVID-19 and patients without COVID-19 (use of standard and droplet precautions only)	0%	..	..	..	..
How many fresh air changes per hour are required in COVID-19 ICUs to reduce cross transmission of SARS-CoV-2?	..	..	..	..	1·0
<6 h	0%	..	..	..	..
≥6 h	100%	..	..	..	..
Air changes per hour is not important	0%	..	..	..	..
Which of the following ICU designs are required for managing patients with COVID-19?	..	..	..	..	0·32
Separate entry and exit for ICUs	38·2%	..	..	..	..
Separate area for PPE donning and doffing	70·6%	..	..	..	..
Separate area for isolation of suspected patients	91·2%	..	..	..	..
Physical barriers between patients and health-care workers	32·4%	..	..	..	..
Cannot comment	0%	..	..	..	..
Which of the following design standards are optimal for AIIRs?	..	..	..	..	0·96
Negative pressure	97·1%	..	..	..	..
Air outlets to the outside of the hospital premises	55·9%	..	..	..	..
Use of a high efficiency particulate air filter with the air outlet	38·2%	..	..	..	..
Use of a high efficiency particulate air filter with both the air inlet and outlet	14·7%	..	..	..	..
Optimal fresh air changes per hour	82·4%	..	..	..	..
No recirculation	11·8%	..	..	..	..
Cannot comment	0%	..	..	..	..
Health-care workers and visitors					
What is the optimal number of shift hours for health-care workers working in COVID-19 ICUs?	..	..	..	..	0·31
< 6 h	0%	..	..	..	..
6–12 h	100%	..	..	..	..
>12 h	0%	..	..	..	..
Cannot comment	0%	..	..	..	..
Health-care workers (nursing staff) managing patients with COVID-19 should not manage patients without COVID-19 during the same shift	91·2%	0%	8·8%	7 (0)	1·0
How frequently should non-vaccinated health-care workers be screened for SARS-CoV-2 by RT-PCR to reduce cross transmission in health care?	..	..	..	..	0·47
Once every 14 days	0%	..	..	..	..
Once every week	11·8%	..	..	..	..
Screening in case of unprotected exposure to a patient with COVID-19 or if symptomatic	94·1%	..	..	..	..
Cannot comment	0%	..	..	..	..
How frequently should vaccinated health-care workers be screened for SARS-CoV-2 by RT-PCR to reduce cross transmission in health care?	..	..	..	..	0·34
Once every 14 days	0%	..	..	..	..
Once every week	2·9%	..	..	..	..
Screening in case of unprotected exposure to patients with COVID-19 or if symptomatic	100%	..	..	..	..
Cannot comment	0%	..	..	..	..

(Table continues on next page)

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See Online for appendix

practice statements might provide guidance on these important aspects of infection control of SARS-CoV-2 in ICUs.

Placement of patients with COVID-19

Public health agencies recommend separation of patients with COVID-19 from other patients;[15–17] however, these

	Agree	Neutral	Disagree	Median (IQR)	χ^2 p value
(Continued from previous page)					
What is the optimal timing for return to work for health-care workers who tested positive for SARS-CoV-2 with mild to moderate illness?*	..	..	..	..	NA
10–14 days from the onset of symptoms (with substantial resolution of symptoms) without RT-PCR tests	20·6%	..	..	..	..
10–14 days from the onset of symptoms (with substantial resolution of symptoms) and a negative RT-PCR tests	35·3%	..	..	..	..
Either of the above are acceptable depending on the local policies, prevalent strain of SARS-CoV-2, and available resources	44·1%	..	..	..	..
What is the best visitor policy for ICUs for patients with COVID-19?	..	..	..	..	0·96
No visitors allowed, only use of video conferencing for communication with patient's family	29·4%	..	..	..	..
Reduced visitation policy (limited by number of visits, duration, person, or specific situations, such as end-of-life care and for paediatric patients)	85·3%	..	..	..	..
Visitor policy same for patients with COVID-19 as for patients without COVID-19 with appropriate PPE use and droplet or aerosol precautions	29·4%	..	..	..	..
Cannot comment	0%	..	..	..	..
All health-care workers working in critical areas should be vaccinated against COVID-19 to reduce cross transmission	100%	0	0	7 (0)	1·0
PPE					
Which of the following PPE use is acceptable for health-care workers working in a COVID-19 ICU?	..	..	..	..	0·36
Full PPE including an N95 mask at all times	29·4%	..	..	..	..
Full PPE including an N95 mask only during AGPs, otherwise use of a surgical mask	82·4%	..	..	..	..
Surgical scrubs with or without a gown with an N95 mask and eye protection or face shield	44·1%	..	..	..	..
Surgical scrubs with or without a gown with a surgical mask	0%	..	..	..	..
Which PPE is acceptable for use during AGPs in ICUs?	..	..	..	..	0·98
Coverall, a surgical mask, surgical gloves, and goggles or a face shield	2·9%	..	..	..	..
Coverall, an N95 (FFP2) mask, surgical gloves, and goggles or a face shield	91·2%	..	..	..	..
Coverall, an FFP3 mask, surgical gloves, and goggles or a face shield	47·1%	..	..	..	..
Coverall, an N95 (FFP2) mask, surgical gloves, goggles, and a face shield	26·5%	..	..	..	..
Coverall, powered air-purifying respirator, and surgical gloves	2·0%	..	..	..	..
Which type of face protection is acceptable for the routine care (non-AGPs) of patients with COVID-19 in ICUs?	..	..	..	..	0·46
Surgical mask	5·9%	..	..	..	..
Surgical mask and a face shield	17·6%	..	..	..	..
N95 mask	23·5%	..	..	..	..
N95 mask and a face shield	85·3%	..	..	..	..
Patients and procedures					
The following are considered AGPs?	..	..	..	..	1·0
Nebulisation	91·2%	..	..	..	..
Bag and mask ventilation	94·1%	..	..	..	..
Non-invasive ventilation	91·2%	..	..	..	..
High-flow nasal oxygen therapy	91·2%	..	..	..	..
Tracheal intubation	94·1%	..	..	..	..
Tracheal extubation	94·1%	..	..	..	..
Tracheostomy	97·1%	..	..	..	..
Open suctioning (oral or tracheal)	94·1%	..	..	..	..
Bronchoscopy	100%	..	..	..	..
Incentive spirometry and deep breathing exercises	67·6%	..	..	..	..
Endoscopy and transoesophageal echocardiography	32·4%	..	..	..	..

(Table continues on next page)

	Agree	Neutral	Disagree	Median (IQR)	χ^2 p value
(Continued from previous page)					
The following measures are recommended to reduce aerosol transmission during tracheal intubation	··	··	··	··	0·89
Adequate PPE (gloves, a gown, an N95 mask or equivalent, and googles or a face shield)	100%	··	··	··	··
Intubation boxes	14·7%	··	··	··	··
Video laryngoscope	88·2%	··	··	··	··
Experienced intubator (airway operator)	94·1%	··	··	··	··
Avoiding bag and mask ventilation	61·8%	··	··	··	··
Success at first attempt (first-pass success)	94·1%	··	··	··	··
Rapid sequence induction	76·5%	··	··	··	··
Cannot comment	0%	··	··	··	··
The following measures might be considered in ICUs to prevent aerosol transmission of SARS-CoV-2	··	··	··	··	0·99
Ventilatory circuit with viral filters for non-invasive or invasive mechanical ventilation	88·2%	··	··	··	··
Closed suction system	100%	··	··	··	··
Video laryngoscopy instead of conventional laryngoscopy for intubation	94·1%	··	··	··	··
Intubation boxes	32·4%	··	··	··	··
Helmet continuous positive airway pressure	58·8%	··	··	··	··
AIIRs	91·2%	··	··	··	··
Increasing outdoor air ventilation rates (opening windows of ICUs)	52·9%	··	··	··	··
Cannot comment	0%	··	··	··	··
When should tracheostomy be considered to facilitate weaning from invasive mechanical ventilation and to reduce the risk of cross transmission of SARS-CoV-2 to health-care workers?	··	··	··	··	0·16
Early (<10 days of ventilation)	5·9%	··	··	··	··
Delayed (≥ 10 days of ventilation)	14·7%	··	··	··	··
Same timing as in patients without COVID-19	94·1%	··	··	··	··
Cannot comment	0%	··	··	··	··
Which of the following technique of performing tracheostomy is preferred in patients with COVID-19-related acute respiratory failure?	··	··	··	··	0·10
Surgical tracheostomy in the operation theatre	17·6%	··	··	··	··
Surgical tracheostomy at the bed side	14·7%	··	··	··	··
Percutaneous tracheostomy with or without bronchoscopy	100%	··	··	··	··
Cannot comment	0%	··	··	··	··
The diagnostic procedures (eg, bronchoalveolar lavage, mini bronchoalveolar lavage, and protected specimen brush) can be performed in patients with COVID-19 as in patients without COVID-19	88·3%	0%	11·7%	6 (1)	··
How should hand hygiene be practiced between patients with COVID-19?	··	··	··	··	0·10
Wear a double pair of gloves and replace outer gloves between patients, and with hand hygiene	17·6%	··	··	··	··
Remove gloves, followed by hand hygiene, and wear a fresh pair of gloves	88·2%	··	··	··	··
Use a hand rub on the gloves between patients	2·9%	··	··	··	··
Cannot comment	2·9%	··	··	··	··
Which of the following steps are acceptable for wash up (including donning) for a sterile procedure (eg, central venous catheter insertion)?	··	··	··	··	0·17
Doffing of the existing PPE, wash up, and don fresh PPE with a sterile gown and gloves	82·4%	··	··	··	··
Wash up before the initial donning of PPE, wear a sterile gown and a pair of sterile gloves just before the procedure	44·1%	··	··	··	··
Wear a sterile gown and a pair of sterile gloves before the procedure with existing PPE	23·5%	··	··	··	··
Cannot comment	0%	··	··	··	··
When can you stop transmission-based precautions for a patient in ICU with severe COVID-19?	··	··	··	··	1·0
20 days from the onset of symptoms (with substantial resolution of symptoms) or 10 days from the onset of symptoms with two negative RT-PCR tests (acceptable depending on the resources)	82·4%	··	··	··	··
20 days from the onset of symptoms (with substantial resolution of symptoms) and two negative RT-PCR tests	23·5%	··	··	··	··
Cannot comment	0%	··	··	··	··
The principles of judicious use of antibiotics (antimicrobial stewardship) should not be altered in patients with COVID-19	100%	0	0	7 (0)	··

(Table continues on next page)

	Agree	Neutral	Disagree	Median (IQR)	χ^2 p value
(Continued from previous page)					
Which team members should be physically present in ICUs for monitoring and surveillance of infection control practices in patients with COVID-19?	..	..	..	..	0·56
Intensivist	91·2%	..	..	..	..
Infection preventionist (eg, infection control nurse, doctor, or clinical microbiologist)	61·8%	..	..	..	..
Infectious disease specialist	8·8%	..	..	..	..
ICU nurse	85·3%	..	..	..	..
Cannot comment	2·9%	..	..	..	..
Waste segregation and management for patients with COVID-19 should be similar to the waste for any other infectious disease	94·1%	2·9	2·9	7 (0)	..
Disinfection and sterilisation					
What are the most suitable strategies for optimising the supply of N95 masks during shortages?	..	..	..	..	0·72
Reuse of N95 masks every 5th day	2·9%	..	..	..	..
Use of reusable elastomeric respirators	8·8%	..	..	..	..
Resterilisation of N95 masks with vaporised hydrogen peroxide (plasma steriliser) or ultraviolet irradiation	11·8%	..	..	..	..
Extended use of N95 masks during the complete shift	91·2%	..	..	..	..
Use of surgical face masks	5·9%	..	..	..	..
Cannot comment	2·9%	..	..	..	..
Which methods of terminal cleaning in ICUs are acceptable (after discharge of patients with COVID-19)?	..	..	..	..	0·95
Use of sodium hypochlorite-based surface cleaning	94·1%	..	..	..	..
Ultra-violet irradiation after surface cleaning	8·8%	..	..	..	..
Vaporised hydrogen peroxide after surface cleaning	20·6%	..	..	..	..
Cannot comment	5·9%	..	..	..	..
What methods of surface cleaning and disinfection are acceptable when a patient with COVID-19 is present in the cubicle?	..	..	..	..	0·07
Surface cleaning with diluted sodium hypochlorite	94·1%	..	..	..	..
Surface cleaning with 70% alcohol	55·9%	..	..	..	..
Surface cleaning with quaternary ammonium compounds	11·8%	..	..	..	..
Cannot comment	5·9%	..	..	..	..
Which of these agents are acceptable for disinfection of (reusable heat sensitive or non-autoclavable) instruments used for airway management (eg, video laryngoscopes) of patients with COVID-19?*	..	..	..	..	0·05
Plasma sterilisation	55·9%	..	..	..	..
Glutaraldehyde (Cidex)	67·6%	..	..	..	..
Para-acetic acid	5·9%	..	..	..	..
Alcohol wipes (70%)	79·4%	..	..	..	..
Cannot comment	8·8%	..	..	..	..

Likert-scale responses are presented as a percentage of agreement, neutral, and disagreement. Consensus was reached when there was more than 70% agreement or disagreement for the Likert scale and more than 80% for multiple-choice type statements. Median and IQR were used to describe the central tendency of responses and dispersion along the central value. The p value was calculated with $\chi^2$and was a measure of stability in responses between the two concluding rounds for each statement. A p value of less than 0·05 was considered as a significant variation or stability not achieved. AGP=aerosol-generating procedure. AIIR=airborne infection isolation room. FFP=filtering face piece. ICU=intensive care unit. NA=not applicable. PPE=personal protective equipment. *Clinical statements that did not reach consensus.

Table: **Consensus and stability analysis of clinical statements on the infection control of SARS-CoV-2 in intensive care units**

recommendations are not uniform. Nosocomial transmission of SARS-CoV-2 is an existent threat.[9] Respiratory support of critically ill patients might result in increased aerosolisation of SARS-CoV-2 with an increased risk of airborne transmission.[4,21] Separation of patients with COVID-19 might be helpful in containing infection and aids in separation of staff and equipment used for patients with COVID-19 and without COVID-19.[5,16] A patient with respiratory symptoms that meets the criteria for the case definition of suspected COVID-19 should be separated from patients with confirmed infection until the diagnosis of the suspected case is confirmed.[16,22] Although patients with COVID-19 should preferably be placed in airborne infection isolation rooms (AIIRs),[15–17] patients can be grouped in ICUs with a distance of at least 1 m between beds when such rooms are not available.[16,17,23]

ICU design and engineering

Guidance from various professional organisations and federal agencies differed on optimal design requirements

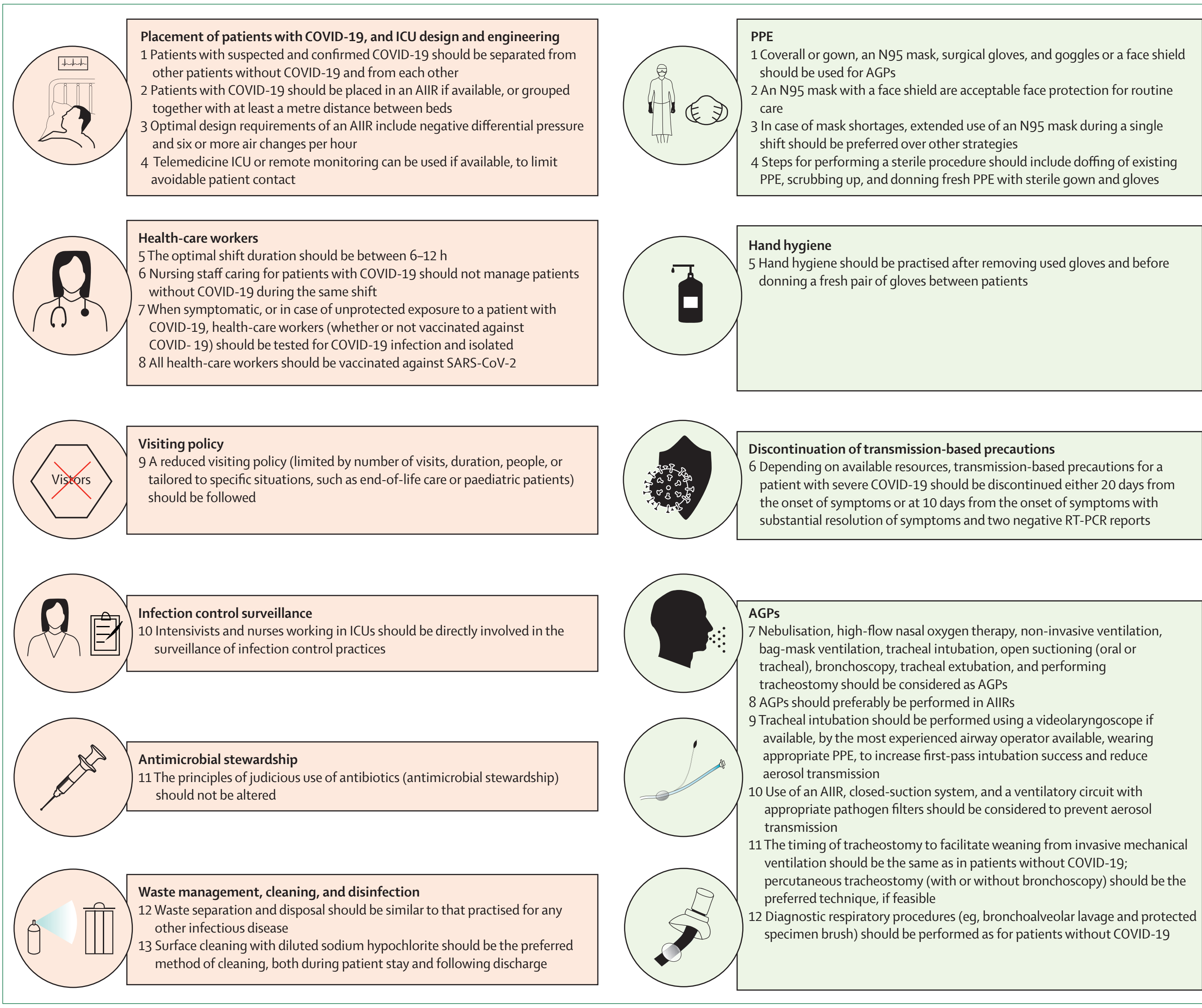

Figure: **Clinical practice statements on infection control of SARS-CoV-2 in ICUs**
AIIR=airborne infection isolation room. AGP=aerosol generating procedure. ICU=intensive care unit. PPE=personal protective equipment.

for AIIRs.[24–26] The US Centers for Disease Control and Prevention (CDC) recommend the use of an AIIR to provide a negative differential pressure, six to 12 air changes per hour depending on the age of construction, and direction of the exhaust of air, either directly outside of the building or via the use of a high efficiency particulate air filter before recirculation.[23] The experts agreed on at least six air changes per hour and negative differential pressure for an AIIR. However, there was no consensus among experts about the type of air outlet to be used for an AIIR.

Telemedicine for remote monitoring can reduce the frequency and duration that staff need to be in contact with patients with COVID-19.[27] There are few case studies describing successful use of telemedicine in the current pandemic.[28,29] There was consensus among the experts for use of telemedicine for remote monitoring, if available, to limit avoidable contact with patients with COVID-19. However, patient care and safety should be considered in the decision making for remote monitoring.

Health-care workers

Human resources are the most valuable part to any health-care system. Therefore, we need to strike a fine balance between providing the best possible care to the current patient and having human resource services remaining for the next patient. Health-care workers working in ICUs are at risk of cross infection and mental

Panel: Research priorities for infection control of SARS-CoV-2 in ICUs

ICU design and patient placement
- Optimal design modifications of existing ICUs to control transmission
- Efficacy and safety of remote monitoring to limit cross transmission
- Optimal patient placement strategy

Health-care worker
- Optimal management of a vaccinated health-care worker following unprotected exposure
- Return-to-work criteria for a health-care worker who has recovered from COVID-19

Aerosol generating procedures
- Risk of aerosols generation with individual procedures
- Impact of various strategies in reducing aerosols generation

PPE
- Optimal PPE required for patient management
- Optimal methods to extend use or reuse of PPE

Transmission-based precautions
- Optimal testing strategy for triage of patients with infection
- Optimal transmission-based precautions for variants of SARS-CoV-2
- Effectiveness of movement restriction strategies to prevent cross transmission
- Optimal strategy for discontinuation of transmission-based precautions

Visitor policy
- Optimal strategy for patient visitation

Disinfection and sterilisation
- Role of alternative agents (eg, ultraviolet devices or hydrogen peroxide systems) for terminal room decontamination

Variants of SARS-CoV-2
- Optimal strategies to prevent transmission

Resource-limited settings and during a surge
- Optimal strategies to prevent transmission

Staff transmission
- Optimal strategies to prevent transmission

ICU=intensive care unit. PPE=personal protective equipment.

stress while providing care to patients with COVID-19. Risk factors associated with a cross transmission include close contact with patients (≥12 times per day), longer contact hours (≥15 h per day), inadequate PPE, or unprotected exposure.[30] The risk of cross transmission is likely to be higher in resource-limited settings and during a surge. In an observational study, the nurse activities score, a surrogate for contact time with patients, was significantly higher in the COVID-19 ICU.[31] Longer shift durations in PPE might cause dehydration, discomfort, medical errors, stress, or mental fatigue.[32] Physical or psychological stress of the health-care worker, risk of cross infection, nurse–patient ratio, and staggered versus continuous shifts should be considered when deciding the duration of the shift.[32]

The CDC recommends that health-care workers assigned to care for patients with COVID-19 should be exclusive in each shift.[16] Consensus was reached in relation to the need for nursing staff but not in relation to the need for medical staff dedicated exclusively to the care of patients with COVID-19 in each shift. One possible reason for this discrepancy might be the challenge of maintaining standards relating to staff–patient ratios during a surge or with diminishing number of patients. Isolation of health-care workers with unprotected exposure to a patient with COVID-19 might affect staff availability.

The available vaccines against COVID-19 might significantly reduce asymptomatic infection and transmission of SARS-CoV-2.[33,34] Therefore, vaccination of all health-care workers against COVID-19 seems an effective strategy to protect frontline health-care workers and reduce cross transmission. Only some aspects of staff transmission specific to ICUs were addressed. Staff transmission among colleagues and other staff members occurs mainly during breaks and mutual gatherings in social rooms. This topic would be of major interest and merits future analysis.

Visiting policy

In the past decade, ICUs worldwide have opened doors for family members, acknowledging the benefits of such practice for both patients and families, with no increased risk of hospital-acquired infection.[35,36] However, hospitals adopted restricted or no-visitor policies during the COVID-19 pandemic. This policy change was intended to mitigate the risk of transmission of infection from visitors to patients and health-care workers or vice versa, and often stemmed from shortage of PPE.[37] With the availability of vaccines, PPE, and a better understanding of SARS-CoV-2 transmission, the experts recommend a reduced visiting policy instead of a complete restriction.[38,39] In some situations, the infrastructure of the COVID-19 ICUs were not conducive for extensive family visitation. The experts agreed on a visitor policy including partial restrictions on the timing, visits, or number of visitors. A case-to-case assessment of transmission risk should be done on the basis of the vaccination status of the visitors and compliance with PPE use. Alternative methods of communication, such as via video or audio, can be considered when feasible. Exceptions from this reduced visiting policy might be considered for paediatric patients and during end-of-life care.[36]

PPE

A higher level of protection is recommended for AGPs due to the risk of airborne SARS-CoV-2. However, recommendations from various public health agencies and experts differ with regards to PPE for AGPs or during routine care of patients with COVID-19.[15–17,40,41] Reasons for differing recommendations include conflicting evidence and shortages of PPE.[42,43] Evidence from outbreaks and simulation experiments have showed that

SARS-CoV-2 transmission occurs through deep breathing or coughing.[10,21,44] Protection with a N95 mask together with a face shield is imperative to reduce nosocomial transmission of SARS-CoV-2.[45,46]

The surge of COVID-19 cases has inundated available health-care resources worldwide and a shortage of N95 masks has caused extended use or reuse during the surge of patients. However, there is scarce and conflicting evidence on the effect of reuse or extended use of masks regarding safety and effectiveness.[47,48] The experts agreed that during periods of short supply, extended use of N95 masks during a single shift was preferable to other strategies.

There is no guidance on preparations for a sterile procedure in a COVID-19 ICU. Invasive procedures, such as central venous catheter insertion, should be performed wearing a sterile gown and gloves as part of the catheter-associated bloodstream infection bundle.[49] Compliance with these requirements can be challenging while wearing PPE. Nevertheless, the experts recommended using a fresh sterile gown and gloves for such procedures, as performed in a patient without COVID-19.

Hand hygiene

Although the incidence of co-infection with community-acquired microbes in patients with COVID-19 is uncommon, the incidence of healthcare-associated infections is higher compared with other patients.[12,50,51] Hand hygiene has a crucial role in breaking the chain of transmission for SARS-CoV-2 within a hospital.[52] However, hand hygiene compliance might be challenging while wearing PPE due to fear of self-contamination.

Discontinuation of transmission-based precautions

Discontinuation of transmission-based precautions is necessary to optimise critical care resources such as AIIR, beds, or PPE. Relaxation of isolation restrictions also enables more effective provision of psychosocial support to patients. However, premature discontinuation might entail risk to public health. The duration of infectivity in a patient with COVID-19 might depend on various factors, such as disease severity, age, and immunity status of the patient.[53,54] SARS-CoV-2 was not detected in 88% of severely ill patients by 10 days of onset of symptoms and was not detected in 95% of critically ill patients by 15 days of onset of symptoms.[55,56] The CDC recommends transmission-based precautions for at least 10 days and up to 20 days from symptom onset, in addition to substantial resolution of symptoms, such as coughs, shortness of breath, and absence of fever without medication for at least 24 h. Repeat testing (by RT-PCR) is no longer recommended for discontinuation of transmission-based precautions.[56] The experts agreed on 20 days from onset of symptoms as a criterion for discontinuation. However, given the different recommendations from public health agencies and the need to optimise the use of ICU beds during patient surges, the experts also agreed that 10 days from the onset of the symptoms and two consecutive negative RT-PCR tests was an acceptable alternative.[56,57]

Aerosol generating procedures

AGPs have been linked to a higher risk of nosocomial transmission of respiratory pathogens. Various public health agencies have recommended a higher level of protection during an AGP, but guidance varies.[15–17] There is a dearth of quality evidence or consensus on the risk posed by different types of AGPs in patients with COVID-19. The evidence is primarily based on small heterogenous studies during the SARS-CoV pandemic, or simulation studies performed in non-ICU settings.[10,58–60] The consensus among the experts for AGPs for patients with COVID-19 is in line with a published systematic review and expert recommendations.[21,40,61]

The experts agreed that AGPs should preferably be performed in AIIRs if available. The studies that examined SARS-CoV-2 stability in different environments and surfaces showed that airborne SARS-CoV-2 could remain viable for up to 3 h.[62] Considering the evidence from the SARS-CoV epidemic and the potential role of airborne transmission of SARS-CoV-2, an AIIR is an effective strategy to control airborne infection and should be used if available.[25,46,63]

Tracheal intubation in patients with COVID-19 is considered a high-risk AGP associated with an increased risk of infection with SARS-CoV-2.[64,65] There has been debate on whether tracheal intubation is an AGP.[59] Tracheal intubation in critically ill patients in the ICU is challenging, unlike controlled settings, such as the operating theatre.[66] A higher risk of cross-infection to health-care workers involved in tracheal intubation of patients with COVID-19 has also been noted.[65]

Various tools have been proposed to reduce risk. Aerosol boxes were initially advocated, but were later found to hinder operator mobility and increase intubation time, intubation difficulty, and PPE tears.[67,68] Recent studies report that experienced intubation teams using appropriate PPE and a video laryngoscope for tracheal intubation had a higher first-pass success rate and had better patient and health-care worker safety procedures.[69–71] Additional recommended strategies to reduce cross transmission include the use of a pathogen filter with ventilator circuits and closed suction systems.[71–74] The clinical practice statements are in line with these recommendations.

Initial concerns about nosocomial transmission of SARS-CoV-2 during tracheostomy resulted in recommendations to delay performing tracheostomy and choose an open surgical tracheostomy over a percutaneous approach.[75,76] Emerging evidence does not support delaying tracheostomy, with no differences in outcome between percutaneous or surgical approaches.[77–79] However, in patients without COVID-19, the percutaneous technique is preferred over a surgical technique whereas evidence supporting early tracheostomy is unclear.[80,81] The experts

Search strategy and selection criteria

A literature search was done with the use of PubMed, MEDLINE, Embase, Google, and Google Scholar for original articles from Jan 1, 2020, to March 28, 2021. We used a combination of keywords: "Infection Control" OR "Hospitals Isolation" OR "Social Isolation" OR "Patient Isolation" OR "Decontamination" OR "Disinfection" OR "Hand Disinfection" OR "Disposable Equipment" OR "Masks" OR "N95 Respirators" OR "Respiratory Protective Devices" OR "Intensive Care Units" OR "Facility Design and Construction" OR "Interior Design and Furnishings" OR "Hospital Planning" OR "Mass Vaccination" OR "Visitors to Patients" OR "Waiting Rooms" OR "Personal Protective Equipment" OR "Rapid Sequence Induction and Intubation" OR "Intubation, Intra-tracheal" OR "Airway Extubation" OR "Suction" OR "Nebulizers and Vaporizers" OR "Spirometry" OR "Bronchoscopy" OR "Endoscopy" OR "Echocardiography" OR "Physical Therapy" OR "Tracheostomy" OR "Disease Transmission" OR "Disease Hotspot" OR "Electronic Prescribing" OR "Telefacsimile" OR "Antimicrobial Stewardship" OR "Waste Management" OR "Glutaral" OR "Ammonium Compounds" AND "COVID-19" OR "SARS-CoV-2". We excluded search results that had non-human study participants, non-English literature, paediatric population, and also publications in the form of abstracts. Guidelines for management of COVID-19 published by WHO, European Centre for Disease Prevention and Control, US Centers for Disease Control and Prevention, Public Health England, and the Victorian Advisory Committee on Infection Control were considered by the steering committee while drafting statements for round one of the Delphi process. SNM, PN, and RJ reviewed the selected papers and established relevance on the basis of the content. The articles were manually sorted and a final reference list of 427 articles was generated, encompassing topics addressed in the Delphi process. The final reference list was then reviewed by the steering committee on the basis of their relevance to topics covered in this Review.

agreed that the timing of tracheostomy to facilitate weaning from invasive mechanical ventilation should be the same as in patients without COVID-19, with percutaneous tracheostomy (with or without bronchoscopy) as the preferred technique. However, in select patients where percutaneous tracheostomy is not suitable or in resource-limited settings, open surgical tracheostomy might be a suitable option.

Bronchoscopy and other invasive respiratory diagnostic respiratory interventions, such as bronchoalveolar lavage or protected specimen brush, are considered AGPs. Initial recommendations to restrict the use of these procedures in patients with COVID-19 were because of concern of infection.[82,83] Alternate techniques with non-bronchoscopic lavage to diagnose infections were proposed.[84] However, with growing experience and availability of adequate PPE, the experts agreed that the same diagnostic procedures can be performed in patients with COVID-19 as for other patients.[85–87]

Infection control surveillance

The surveillance of infection control practices in COVID-19 ICUs can be challenging due to an increased workload, PPE availability, reduced number of health-care workers allowed into ICUs, and altered practices.[13,88] Therefore, the experts agreed that the intensivists and nurses working in the ICU should be part of the surveillance team for infection control practices.

Antimicrobial stewardship

Clinicians are concerned about bacterial and fungal co-infection in severe viral pneumonia. The evidence suggests that bacterial co-infection with COVID-19 is relatively uncommon: 3·5–7% of hospitalised patients and 8–14% of ICU patients. Bacterial co-infection rates are also lower than in patients with influenza.[13,89–91] Although this lower rate does not support the empirical use of antibiotics in patients with COVID-19, the usage of antibiotics is high, especially in ICU patients.[92–94] In a multicentre cohort study of 13 932 patients, 11 062 (79·4%) were prescribed empirical antibiotics, nearly a third (34·2%) of prescriptions were inappropriate.[95] Antimicrobial stewardship has been substantially affected by the COVID-19 pandemic due to the disruption of microbiological surveillance and altered infection control practices.[96] The experts agreed on the application of the usual principles of antimicrobial stewardship for the management of COVID-19.

Waste management, cleaning, and disinfection

The primary mode of transmission with SARS-CoV-2 is through droplets and aerosols. However, fomites have a minor but important role in the chain of transmission.[97] Waste generated from patients with COVID-19 needs to be managed in a similar manner to infectious waste from other patients.[98] Surface and environmental disinfection is an important strategy to control SARS-CoV-2 transmission. Sodium hypochlorite has been recommended as the preferred agent for surface cleaning during patient stay and after discharge because of its broad-spectrum antimicrobial activity, including *Candida auris* and *Clostridioides difficile*.[99–101]

Dissensus among the experts

Despite several iterative Delphi rounds, two clinical statements did not reach the desired consensus. There was disagreement among experts on the optimal return to work criteria for a health-care worker who recovers from mild to moderate COVID-19. The experts were divided between two strategies: substantial resolution of symptoms alone or in combination with RT-PCR testing. This divide in decision might be due to the varying recommendations by public health agencies.[15,17,57] The CDC recommends against a test-based strategy, as in the majority of cases, a positive RT-PCR after 10 days reflects shedding of non-replicating virus.[15] However, other public health agencies and experts recommend different criteria depending on the need for hospitalisation, time from exposure, symptom-free period, and tests performed.[17,57,102] The difference in guidance can also be explained by a delicate balance to be attained between optimal infection control strategies and potential health-care worker shortages by public health agencies. There was no consensus among experts on an acceptable disinfection strategy for heat-sensitive instruments used for airway management in patients with COVID-19. The dissensus might be because of the preferred use of single use instruments for airway management in these patients.

Strengths and limitations

Our study has several strengths. First, this Review is the first of its kind to develop expert clinical practice statements on infection control for SARS-CoV-2 in ICUs, an area in which robust evidence is scarce. Second, our panel included experts in infectious disease, infection control, sepsis, respiratory failure, and intensive care medicine from diverse geographical regions, representing both resource-rich and resource-limited settings. The experts' responses reflect their own local availability and practices. Third, to avoid bias from dominance and group pressure, the anonymity of the experts and their individual responses were preserved until the completion of the Delphi rounds. Fourth, we completed four Delphi rounds, maintaining a tight timeline (less than a month) despite the busy clinical responsibilities of the experts, with an attrition rate of only 3%. Finally, we were able to reach agreement in 94% of our clinical statements. We believe that this Review provides important information, which could complement existing guidelines by including the viewpoints from frontline clinicians who have dealt with the problems referred to.

The study has some limitations. All clinical settings might not be captured with a dichotomous approach used in a few practice statements; a more personalised approach might be required for some clinical interventions. Since this study was specific to infection control in ICUs, emergency providers who also care for acutely ill patients with COVID-19 were not included as experts. Resource-limited settings that are overwhelmed might struggle to follow the clinical practice statements. In addition, protecting health-care workers in resource-limited settings and providing guidance for dealing with equipment shortages have not been studied in detail, because this was beyond the scope of our work, and should be included as future research priorities. Only some aspects of staff transmission specific to ICUs were addressed and merits further evaluation.

New variants of SARS-CoV-2 might be more infectious or more pathogenic. Therefore, the potential relevance or applicability of these consensus statements for new variants is not known. Although, the variants might not modify or markedly affect the present findings, this needs to be investigated further. It is also possible that interpretation of the statements might have influenced the responses received from the experts. However, feedback from the experts (allowed in all the rounds) and the stability of the responses should have ensured fidelity of the responses and minimised individual bias. Factors such as non-availability of a few modalities and variation in local or national guidelines might have affected the experts' opinion. Lastly, evidence is emerging in this area and best practices can change as the evidence evolves.

Conclusions

Using a Delphi process, consensus was reached by an international group of experts on 31 statements on infection control of SARS-CoV-2 in ICUs. The 25 clinical practice statements issued address important aspects of infection control, including ICU design and engineering, health-care worker safety, visiting policy, PPE, patients and procedures, disinfection, and sterilisation. Further studies are needed to identify the beneficial effects of these statements and address the remaining uncertainties.

Contributors

The steering committee included SNM, PN, RJ, EA, AC, JVD, CR, and VDR. SNM served as a moderator of the working group. PN, SNM, and RJ contributed to the conceptualisation, design of the work, data curation, formal analysis, methodology, project administration, resources, software, verification of the underlying data, and drafting of the manuscript. EA, AC, JVD, CR, and VDR contributed to the design of the work, data acquisition, data interpretation, and drafting of the manuscript. PN and RJ did the literature search and formal analysis. PN and SNM prepared the figures. The experts (WA, YMA, JB, MB, JDW, GD, BD, SE, LE, SF, CG, NEH, SJ, RMK, YK, MK, MML, FRM, JM, IM-L, MM, MSN, PP, AP, JVP, JP, LP, MWP, AR, MJS, MS, JF-T, BV, J-LV, and TW) completed the survey questionnaires in the various rounds of the Delphi process, the results of which were used to draft the expert clinical practice statements. All authors contributed to reviewing and editing of the manuscript for intellectual content and are responsible for the content of this Review.

Declaration of interests

PN reports honoraria for lectures and other educational events from Tabuk Pharmaceuticals, and is a member of Edward Lifesciences Advisory Board Panel, outside of the submitted work. JVD reports personal fees (paid to institution) from Edwards India, outside the submitted work. MB reports honoraria for lectures and another educational event from Angelini, Bayer, bioMérieux, Cipla, Gilead Sciences, Menarini, Merck Sharp & Dohme (MSD), Pfizer, and Shionogi; grants from Pfizer and MSD, outside of the submitted work; and is on the advisory board of Cidara Therapeutics. JDW reports honoraria (paid to institution) for lectures and other educational events from MSD and Pfizer, outside of the submitted work. BD reports research grants from Ministry of Science and Technology, People's Republic of China (research grant 2020YFC0841300), and Chinese Academy of Medical Sciences Innovation Fund for Medical Sciences (2020-I2M-2-005 and 2019-I2M-1-001), outside of the submitted work. LE reports consulting fees (paid to institution) for the National Emerging Special Pathogen Training and Education Centre, outside of the submitted work. SJ reports academic consultation fees from Drager, Fisher-Paykel, Medtronic, Baxter International, and Fresenius–Xenios; and honoraria for lectures and other educational events from Fisher-Paykel and Baxter, outside of the submitted work. MK reports honoraria from Merck and Pfizer for lectures and other educational events, outside of the submitted work. JM reports research grants (paid to institution)

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