



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

Prashant Nasa, Elie Azoulay, Arunaloke Chakrabarti, Jigeeshu Divatia, Ravi Jain, Camilla Rodrigues, Victor Rosenthal, Waleed Alhazzani, Yaseen Arabi, Jan Bakker, et al.

► To cite this version:

Prashant Nasa, Elie Azoulay, Arunaloke Chakrabarti, Jigeeshu Divatia, Ravi Jain, et al.. Infection control in the intensive care unit: expert consensus statements for SARS-CoV-2 using a Delphi method. The Lancet Infectious Diseases, 2021, 10.1016/S1473-3099(21)00626-5 . hal-03430305

HAL Id: hal-03430305

<https://hal.science/hal-03430305>

Submitted on 16 Nov 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

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

Prashant Nasa, Elie Azoulay, Arunaloake Chakrabarti, Jigeeshu V Divatia, Ravi Jain, Camilla Rodrigues, Victor D Rosenthal, Waleed Alhazzani, Yaseen M Arabi, Jan Bakker, Matteo Bassetti, Jan De Waele, George Dimopoulos, Bin Du, Sharon Einav, Laura Evans, Simon Finfer, Claude Guérin, Naomi E Hammond, Samir Jaber, Ruth M Kleinpell, Younsuck Koh, Marin Kollef, Mitchell M Levy, Flavia R Machado, Jordi Mancebo, Ignacio Martin-Loeches, Mervyn Mer, Michael S Niederman, Paolo Pelosi, Anders Perner, John V Peter, Jason Phua, Lise Piquilloud, Mathias W Pletz, Andrew Rhodes, Marcus J Schultz, Mervyn Singer, Jean-François Timsit, Balasubramanian Venkatesh, Jean-Louis Vincent, Tobias Welte, Sheila N Myatra

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.

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

(P Nasa MD); Saint-Louis Teaching Hospital, APHP, University of Paris, Paris, France (Prof E Azoulay PhD); Postgraduate Institute of Medical Education and Research, Chandigarh, India (Prof A Chakrabarti MD); Tata Memorial Hospital, Homi Bhabha National Institute, Mumbai, India (Prof J V Divatia MD); Mahatma Gandhi Medical College and Hospital, Jaipur, India (R Jain MD); PD Hinduja National Hospital and Medical Research Centre, Mumbai, India (C Rodrigues MD); International Nosocomial Infection Control Consortium, Miami, FL, USA (Prof V D Rosenthal MD); McMaster University, Hamilton, ON, Canada (Prof W Alhazzani MD); King Saud bin Abdulaziz University for Health Sciences, Riyadh, Saudi Arabia (Prof Y M Arabi MD); King Abdullah International Medical Research Center, Riyadh, Saudi Arabia (Prof Y M Arabi MD); New York University Grossman School of Medicine, New York, NY, USA (Prof J Bakker PhD); Columbia University Vagelos College of Physicians and Surgeons, New York, NY, USA (Prof J Bakker); Erasmus University Medical Center, Rotterdam, Netherlands (Prof J Bakker); Pontificia Universidad Católica de Chile, Santiago, Chile (Prof J Bakker); Department of Health Sciences, University of Genoa, Genoa, Italy (Prof M Bassetti PhD); Ghent University Hospital, Ghent, Belgium

(Prof J De Waele PhD); Attikon University Hospital, Athens, Greece (Prof G Dimopoulos PhD); National and Kapodistrian University of Athens, School of Medicine, Athens, Greece (Prof G Dimopoulos); State Key Laboratory of Rare, Complex and Critical Diseases, Peking Union Medical College Hospital, Peking Union Medical College and Chinese Academy of Medical Sciences, Beijing, China (Prof B Du MD); Shaare Zedek Medical Center, Jerusalem, Israel (Prof S Einav MD); Faculty of Medicine, Hebrew University, Jerusalem, Israel (Prof S Einav); University of Washington, Seattle, WA, USA (Prof L Evans MD); The George Institute for Global Health, University of New South Wales, Sydney, NSW, Australia (Prof S Finfer MD, N E Hammond PhD); Imperial College London, London, UK (Prof S Finfer); University de Lyon, Lyon, France (Prof C Guérin MD); Institut Mondor de Recherches Biomédicales, Créteil, France (Prof C Guérin); Malcolm Fisher Department of Intensive Care, Royal North Shore Hospital, Newton, Adelaide, SA, Australia (N E Hammond); Hôpital Saint-Éloi, Montpellier University Hospital, Montpellier, France (Prof S Jaber PhD); Vanderbilt University School of Nursing, Vanderbilt University, Nashville, TN, USA (Prof R M Kleinpell PhD); College of Medicine, University of Ulsan College of Medicine, University of Ulsan, Seoul, South Korea (Prof Y Koh MD); Washington University School of Medicine, Washington University, St Louis, MO, USA (Prof M Kollef MD); Warren Alpert Medical School, Brown University, Providence, RI, USA (Prof M M Levy MD); Hospital Sao Paulo, Universidade Federal de São Paulo, São Paulo, Brazil (Prof F R Machado PhD); Hospital de Sant Pau, Barcelona, Spain (Prof J Mancebo MD); St James's Hospital, Dublin, Ireland (Prof I Martin-Loeches PhD); Charlotte Maxeke Johannesburg Academic Hospital, Johannesburg, South Africa (Prof M Mer PhD); Faculty of Health Sciences

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 COVID-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)

University of the Witwatersrand, Johannesburg, South Africa (Prof M Mer); Weill Cornell Medical Center, New York, NY, USA (Prof M S Niederman MD); IRCCS for Oncology and Neurosciences, San Martino Policlinico Hospital, Genoa, Italy (Prof P Pelosi MD); University of Genoa, Genoa, Italy (Prof P Pelosi); Rigshospitalet, Copenhagen University Hospital, Copenhagen, Denmark (Prof A Perner PhD); Christian Medical College, Vellore, India (Prof J V Peter FCIM); Alexandra Hospital (Prof J Phua MRCP) and National University Hospital (Prof J Phua), National University Health System, Singapore (Prof J Phua); University Hospital and University of Lausanne, Lausanne, Switzerland (Prof L Piquilloud PhD); Institute of Infectious Diseases and Infection Control, Jena University Hospital, Jena, Germany (Prof M W Pletz MD); St George's University Hospitals NHS Foundation Trust, London, UK (Prof A Rhodes MD); Amsterdam University Medical Centers, Locatie AMC, Amsterdam, Netherlands (Prof M J Schultz PhD); Mahidol Oxford Tropical Medicine Research Unit, Mahidol University, Bangkok, Thailand (Prof M J Schultz); Nuffield Department of Medicine, University of Oxford, Oxford, UK (Prof M J Schultz); University College London, London, UK (Prof M Singer FRCP); APHP, Hôpital Bichat Medical, IAME, University of Paris, Paris, France (Prof J-F Timsit PhD); The Wesley Hospital, Brisbane, QLD, Australia (Prof B Venkatesh MD); Université Libre de Bruxelles, Bruxelles, Belgium (Prof J-L Vincent PhD); German Center of Lung Research, Hannover, Germany (Prof T Welte MD); Department of Anaesthesia, Critical Care and Pain, Tata Memorial Hospital, Homi Bhabha National Institute, Mumbai, India (Prof S N Myatra MD)

Correspondence to: Prof Sheila Nainan Myatra, Department of Anaesthesia, Critical Care and Pain, Tata Memorial Hospital, Mumbai 400012, India sheila150@hotmail.com

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%	..	..	..	..
AllRs	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 (\geq 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 χ^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

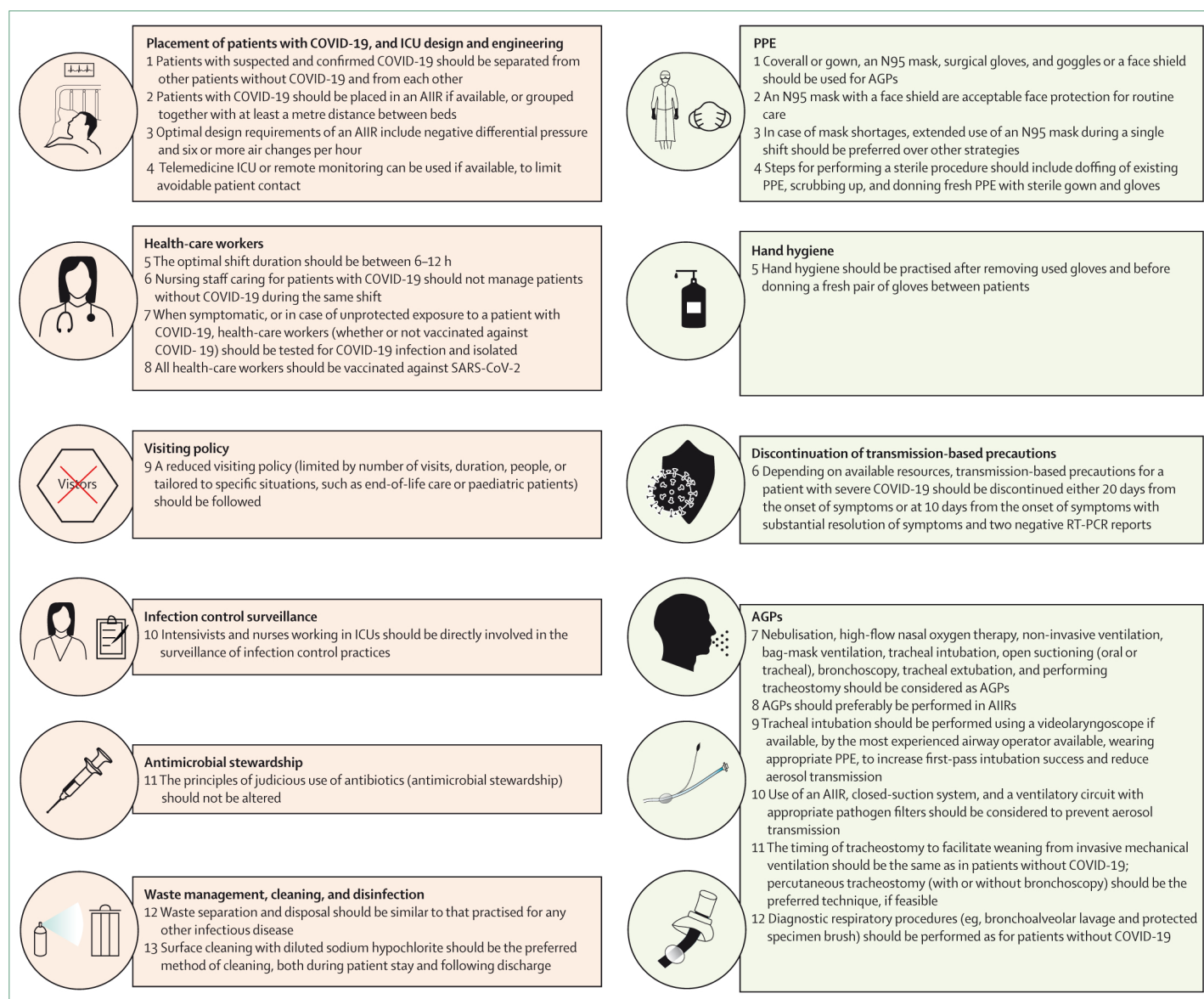


Figure: Clinical practice statements on infection control of SARS-CoV-2 in ICUs

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-Kenios; 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)

from Covidien (Medtronic) and Canadian Institutes of Health Research; personal consultation fees from Janssen Pharmaceuticals and Faron Pharmaceuticals; honoraria from Medtronic for lectures and other educational events; and a consulting agreement signed with Vyair, outside of the submitted work. MSN reports personal consulting fees from Abbvie, outside of the submitted work. AP reports research grants from Novo Nordisk Foundation, Pfizer, and Fresenius Kabi, outside of the submitted work. MS reports research grants and advisory board fees from NewB; research grants from DSTL, Critical Pressure, and Apollo Therapeutics; speaking fees (paid to institution) from Amomed, advisory board fees from Biotest, GE, Baxter, Roche, and Bayer; and honoraria from Shionogi, outside of the submitted work. BV reports research grants and honoraria for the guest lecture and other educational events from Baxter, outside of the submitted work. All other authors declare no competing interests.

References

- WHO. Infection prevention and control during health care when novel coronavirus (nCoV) infection is suspected. Geneva: World Health Organization, 2020.
- Kenarkoobi A, Noorimotlagh Z, Falahi S, et al. Hospital indoor air quality monitoring for the detection of SARS-CoV-2 (COVID-19) virus. *Sci Total Environ* 2020; **748**: 141324.
- Noorimotlagh Z, Jaafarzadeh N, Martinez SS, Mirzaee SA. A systematic review of possible airborne transmission of the COVID-19 virus (SARS-CoV-2) in the indoor air environment. *Environ Res* 2021; **193**: 110612.
- Greenhalgh T, Jimenez JL, Prather KA, Tufekci Z, Fisman D, Schooley R. Ten scientific reasons in support of airborne transmission of SARS-CoV-2. *Lancet* 2021; **397**: 1603–05.
- Centers for Disease Control and Prevention. Scientific brief: SARS-CoV-2 transmission. May 7, 2021. <https://www.cdc.gov/coronavirus/2019-ncov/science/science-briefs/sars-cov-2-transmission.html> (accessed May 15, 2021).
- WHO. Transmission of SARS-CoV-2: implications for infection prevention precautions. Geneva: World Health Organization, 2020.
- Oda G, Sharma A, Lucero-Obusan C, Schirmer P, Sohoni P, Holodniy M. COVID-19 infections among healthcare personnel in the United States Veterans Health Administration, March to August, 2020. *J Occup Environ Med* 2021; **63**: 291–95.
- Nguyen LH, Drew DA, Graham MS, et al. Risk of COVID-19 among front-line health-care workers and the general community: a prospective cohort study. *Lancet Public Health* 2020; **5**: e475–83.
- Abbas M, Robalo Nunes T, Martischang R, et al. Nosocomial transmission and outbreaks of coronavirus disease 2019: the need to protect both patients and healthcare workers. *Antimicrob Resist Infect Control* 2021; **10**: 7.
- Brown J, Gregson FKA, Shrimpton A, et al. A quantitative evaluation of aerosol generation during tracheal intubation and extubation. *Anaesthesia* 2021; **76**: 174–81.
- WHO. Prevention, identification and management of health worker infection in the context of COVID-19. Geneva: World Health Organization, 2020.
- Grasselli G, Scaravilli V, Mangioni D, et al. Hospital-acquired infections in critically ill patients with COVID-19. *Chest* 2021; **160**: 454–65.
- Phua J, Weng L, Ling L, et al. Intensive care management of coronavirus disease 2019 (COVID-19): challenges and recommendations. *Lancet Respir Med* 2020; **8**: 506–17.
- Goh KJ, Wong J, Tien JC, et al. Preparing your intensive care unit for the COVID-19 pandemic: practical considerations and strategies. *Crit Care* 2020; **24**: 215.
- Public Health England. COVID-19: infection prevention and control guidance. Jan 10, 2020. <https://www.gov.uk/government/publications/wuhan-novel-coronavirus-infection-prevention-and-control> (accessed May 10, 2021).
- Centers for Disease Control and Prevention. Interim infection prevention and control recommendations for healthcare personnel during the coronavirus disease 2019 (COVID-19) pandemic. Feb 23, 2021. <https://www.cdc.gov/coronavirus/2019-ncov/hcp/infection-control-recommendations.html> (accessed May 10, 2021).
- WHO. Infection prevention and control during health care when coronavirus disease (COVID-19) is suspected or confirmed. Geneva: World Health Organization, 2020.
- Diamond IR, Grant RC, Feldman BM, et al. Defining consensus: a systematic review recommends methodologic criteria for reporting of Delphi studies. *J Clin Epidemiol* 2014; **67**: 401–09.
- Nasa P, Jain R, Juneja D. Delphi methodology in healthcare research: how to decide its appropriateness. *World J Methodol* 2021; **11**: 116–29.
- Jünger S, Payne SA, Brine J, Radbruch L, Brearley SG. Guidance on Conducting and Reporting DELphi Studies (CREDES) in palliative care: recommendations based on a methodological systematic review. *Palliat Med* 2017; **31**: 684–706.
- Klompas M, Baker M, Rhee C. What is an aerosol-generating procedure? *JAMA Surg* 2021; **156**: 113–14.
- Sperna Weiland NH, Traversari RAAL, Sinnige JS, et al. Influence of room ventilation settings on aerosol clearance and distribution. *Br J Anaesth* 2021; **126**: e49–52.
- Centers for Disease Control and Prevention. Guideline for isolation precautions: preventing transmission of infectious agents in healthcare settings. 2007. <https://www.cdc.gov/infectioncontrol/guidelines/isolation/glossary.html> (accessed May 10, 2021).
- American Institute of Architects. ANSI/ASHRAE/ASHE standard 170–2017: ventilation of health care facilities. Atlanta, GA: The American Society of Heating, Refrigerating and Air Conditioning Engineers, 2008.
- UK Department of Health. Health building note 04-01 supplement 1: isolation facilities for infectious patients in acute settings. London: Department of Health and Social Care, 2009.
- Victorian Advisory Committee on Infection Control. Guidelines for the classification and design of isolation rooms in health care facilities. Melbourne, VIC: Department of Human Services.
- Aziz S, Arabi YM, Alhazzani W, et al. Managing ICU surge during the COVID-19 crisis: rapid guidelines. *Intensive Care Med* 2020; **46**: 1303–25.
- Dhala A, Sasangohar F, Kash B, Ahmadi N, Masud F. Rapid implementation and innovative applications of a virtual intensive care unit during the COVID-19 pandemic: case study. *J Med Internet Res* 2020; **22**: e20143.
- Krouss M, Allison MG, Rios S, et al. Rapid implementation of telecritical care support during a pandemic: lessons learned during the coronavirus disease 2020 surge in New York City. *Crit Care Explor* 2020; **2**: e0271.
- Shaukat N, Ali DM, Razzak J. Physical and mental health impacts of COVID-19 on healthcare workers: a scoping review. *Int J Emerg Med* 2020; **13**: 40.
- Bruyneel A, Gallani MC, Tack J, et al. Impact of COVID-19 on nursing time in intensive care units in Belgium. *Intensive Crit Care Nurs* 2021; **62**: 102967.
- Kluger DM, Aizenbud Y, Jaffe A, et al. Impact of healthcare worker shift scheduling on workforce preservation during the COVID-19 pandemic. *Infect Control Hosp Epidemiol* 2020; **41**: 1443–45.
- Angel Y, Spitzer A, Henig O, et al. Association between vaccination with BNT162b2 and incidence of symptomatic and asymptomatic SARS-CoV-2 infections among health care workers. *JAMA* 2021; **325**: 2457–65.
- Shah ASV, Gribben C, Bishop J, et al. Effect of vaccination on transmission of COVID-19: an observational study in healthcare workers and their households. *medRxiv* 2021; published online March 21. <https://doi.org/10.1101/2021.03.11.21253275> (preprint).
- Nassar Junior AP, Besen BAMP, Robinson CC, Falavigna M, Teixeira C, Rosa RG. Flexible versus restrictive visiting policies in ICUs: a systematic review and meta-analysis. *Crit Care Med* 2018; **46**: 1175–80.
- Ciufo D, Hader R, Holly C. A comprehensive systematic review of visitation models in adult critical care units within the context of patient- and family-centred care. *Int J Evid-Based Healthc* 2011; **9**: 362–87.
- Rose L, Yu L, Casey J, et al. Communication and virtual visiting for families of patients in intensive care during the COVID-19 pandemic: a UK national survey. *Ann Am Thorac Soc* 2021; **18**: 1685–92.
- Munshi L, Evans G, Razak F. The case for relaxing no-visitor policies in hospitals during the ongoing COVID-19 pandemic. *CMAJ* 2021; **193**: E135–37.
- Centers for Disease Control and Prevention. Management of visitors to healthcare facilities in the context of COVID-19: non-US healthcare settings. Sept 15, 2020. <https://www.cdc.gov/coronavirus/2019-ncov/hcp/non-us-settings/hcf-visitors.html>. (accessed July 10, 2021).

- 40 Nasa P, Azoulay E, Khanna AK, et al. Expert consensus statements for the management of COVID-19-related acute respiratory failure using a Delphi method. *Crit Care* 2021; **25**: 106.
- 41 Wei H, Jiang B, Behringer EC, et al. Controversies in airway management of COVID-19 patients: updated information and international expert consensus recommendations. *Br J Anaesth* 2021; **126**: 361–66.
- 42 Jefferson T, Del Mar CB, Dooley L, et al. Physical interventions to interrupt or reduce the spread of respiratory viruses. *Cochrane Database Syst Rev* 2020; **11**: CD006207.
- 43 WHO. Critical shortage or lack of personal protective equipment in the context of COVID-19. Western Pacific region: World Health Organization, 2020.
- 44 Hamilton F, Arnold D, Bzdek BR, et al. Aerosol generating procedures: are they of relevance for transmission of SARS-CoV-2? *Lancet Respir Med* 2021; **9**: 687–89.
- 45 Chu DK, Akl EA, Duda S, et al. Physical distancing, face masks, and eye protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19: a systematic review and meta-analysis. *Lancet* 2020; **395**: 1973–87.
- 46 Fink JB, Ehrmann S, Li J, et al. Reducing aerosol-related risk of transmission in the era of COVID-19: an interim guidance endorsed by the International Society of Aerosols in Medicine. *J Aerosol Med Pulm Drug Deliv* 2020; **33**: 300–04.
- 47 Toomey EC, Conway Y, Burton C, et al. Extended use or reuse of single-use surgical masks and filtering face-piece respirators during the coronavirus disease 2019 (COVID-19) pandemic: a rapid systematic review. *Infect Control Hosp Epidemiol* 2021; **42**: 75–83.
- 48 Company Sancho MC, González-María E, Abad-Corpa E. Limited reuse and extended use of filtering facepiece respirators. *Enferm Clin* 2021; **31** (suppl 1): S78–83.
- 49 Marshall J, Mermel LA, Fakih M, et al. Strategies to prevent central line-associated bloodstream infections in acute care hospitals: 2014 update. *Infect Control Hosp Epidemiol* 2014; **35**: 753–71.
- 50 Soriano MC, Vaquero C, Ortiz-Fernández A, Caballero A, Blandino-Ortiz A, de Pablo R. Low incidence of co-infection, but high incidence of ICU-acquired infections in critically ill patients with COVID-19. *J Infect* 2021; **82**: e20–21.
- 51 Baskaran V, Lawrence H, Lansbury LE, et al. Co-infection in critically ill patients with COVID-19: an observational cohort study from England. *J Med Microbiol* 2021; **70**: 001350.
- 52 Zhang GQ, Pan HQ, Hu XX, et al. The role of isolation rooms, facemasks and intensified hand hygiene in the prevention of nosocomial COVID-19 transmission in a pulmonary clinical setting. *Infect Dis Poverty* 2020; **9**: 104.
- 53 van Kampen JJA, van de Vijver DAMC, Fraaij PLA, et al. Duration and key determinants of infectious virus shedding in hospitalized patients with coronavirus disease-2019 (COVID-19). *Nat Commun* 2021; **12**: 267.
- 54 Rhee C, Kanjilal S, Baker M, Klompas M. Duration of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infectivity: when is it safe to discontinue isolation? *Clin Infect Dis* 2021; **72**: 1467–74.
- 55 Mallett S, Allen AJ, Graziadio S, et al. At what times during infection is SARS-CoV-2 detectable and no longer detectable using RT-PCR-based tests? A systematic review of individual participant data. *BMC Med* 2020; **18**: 346.
- 56 Centre for Disease Control and Prevention. Interim infection prevention and control recommendations for healthcare personnel during the coronavirus disease 2019 (COVID-19) pandemic. <https://www.cdc.gov/coronavirus/2019-ncov/hcp/infection-control-recommendations.html> (accessed Sept 12, 2021).
- 57 European Centre for Disease Prevention and Control. Guidance for discharge and ending of isolation of people with COVID-19: technical report. Stockholm: European Centre for Disease Prevention and Control, 2020.
- 58 Tran K, Cimon K, Severn M, Pessoa-Silva CL, Conly J. Aerosol generating procedures and risk of transmission of acute respiratory infections to healthcare workers: a systematic review. *PLoS One* 2012; **7**: e35797.
- 59 Nestor CC, Wang S, Irwin MG. Are tracheal intubation and extubation aerosol-generating procedures? *Anaesthesia* 2021; **76**: 151–55.
- 60 Wilson NM, Marks GB, Eckhardt A, et al. The effect of respiratory activity, non-invasive respiratory support and facemasks on aerosol generation and its relevance to COVID-19. *Anaesthesia* 2021; **76**: 1465–74.
- 61 Jackson T, Deibert D, Wyatt G, et al. Classification of aerosol-generating procedures: a rapid systematic review. *BMJ Open Respir Res* 2020; **7**: e000730.
- 62 van Doremalen N, Bushmaker T, Morris DH, et al. Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. *N Engl J Med* 2020; **382**: 1564–67.
- 63 Tang S, Mao Y, Jones RM, et al. Aerosol transmission of SARS-CoV-2? Evidence, prevention and control. *Environ Int* 2020; **144**: 106039.
- 64 Yao W, Wang T, Jiang B, et al. Emergency tracheal intubation in 202 patients with COVID-19 in Wuhan, China: lessons learnt and international expert recommendations. *Br J Anaesth* 2020; **125**: e28–37.
- 65 El-Boghdadly K, Wong DJN, Owen R, et al. Risks to healthcare workers following tracheal intubation of patients with COVID-19: a prospective international multicentre cohort study. *Anaesthesia* 2020; **75**: 1437–47.
- 66 Russotto V, Myatra SN, Laffey JG, et al. Intubation practices and adverse peri-intubation events in critically ill patients from 29 countries. *JAMA* 2021; **325**: 1164–72.
- 67 Noor Azhar M, Bustam A, Poh K, et al. COVID-19 aerosol box as protection from droplet and aerosol contaminations in healthcare workers performing airway intubation: a randomised cross-over simulation study. *Emerg Med J* 2021; **38**: 111–17.
- 68 Feldman O, Samuel N, Kvatinisky N, Idelman R, Diamand R, Shavit I. Endotracheal intubation of COVID-19 patients by paramedics using a box barrier: a randomized crossover manikin study. *PLoS One* 2021; **16**: e0248383.
- 69 Ahmad I, Jeyarajah J, Nair G, et al. A prospective, observational, cohort study of airway management of patients with COVID-19 by specialist tracheal intubation teams. *Can J Anaesth* 2021; **68**: 196–203.
- 70 Gandhi A, Sokhi J, Lockie C, Ward PA. Emergency tracheal intubation in patients with COVID-19: experience from a UK centre. *Anesthesiol Res Pract* 2020; **2020**: 8816729.
- 71 Sorbello M, El-Boghdadly K, Di Giacinto I, et al. The Italian coronavirus disease 2019 outbreak: recommendations from clinical practice. *Anaesthesia* 2020; **75**: 724–32.
- 72 Chan MTV, Chow BK, Lo T, et al. Exhaled air dispersion during bag-mask ventilation and sputum suctioning—implications for infection control. *Sci Rep* 2018; **8**: 198.
- 73 Kaur R, Weiss TT, Perez A, et al. Practical strategies to reduce nosocomial transmission to healthcare professionals providing respiratory care to patients with COVID-19. *Crit Care* 2020; **24**: 571.
- 74 Imbriaco G, Monesi A. Closed tracheal suctioning systems in the era of COVID-19: is it time to consider them as a gold standard? *J Infect Prev* 2021; **22**: 44–45.
- 75 Takhar A, Walker A, Tricklebank S, et al. Recommendation of a practical guideline for safe tracheostomy during the COVID-19 pandemic. *Eur Arch Otorhinolaryngol* 2020; **277**: 2173–84.
- 76 Chiesa-Estomba CM, Lechien JR, Calvo-Henríquez C, et al. Systematic review of international guidelines for tracheostomy in COVID-19 patients. *Oral Oncol* 2020; **108**: 104844.
- 77 Kwak PE, Connors JR, Benedict PA, et al. Early outcomes from early tracheostomy for patients with COVID-19. *JAMA Otolaryngol Head Neck Surg* 2021; **147**: 239–44.
- 78 Rovira A, Tricklebank S, Surda P, et al. Open versus percutaneous tracheostomy in COVID-19: a multicentre comparison and recommendation for future resource utilisation. *Eur Arch Otorhinolaryngol* 2021; **278**: 2107–14.
- 79 Long SM, Chern A, Feit NZ, et al. Percutaneous and open tracheostomy in patients with COVID-19: comparison and outcomes of an institutional series in New York City. *Ann Surg* 2021; **273**: 403–09.
- 80 Brass P, Hellmich M, Ladra A, Ladra J, Wrzosek A. Percutaneous techniques versus surgical techniques for tracheostomy. *Cochrane Database Syst Rev* 2016; **7**: CD008045.
- 81 Wang R, Pan C, Wang X, Xu F, Jiang S, Li M. The impact of tracheostomy timing in critically ill patients undergoing mechanical ventilation: a meta-analysis of randomized controlled clinical trials with trial sequential analysis. *Heart Lung* 2019; **48**: 46–54.

- 82 Luo F, Darwiche K, Singh S, et al. Performing bronchoscopy in times of the COVID-19 pandemic: practice statement from an international expert panel. *Respiration* 2020; **99**: 417–22.
- 83 Ora J, Puxeddu E, Cavalli F, et al. Does bronchoscopy help the diagnosis in COVID-19 infection? *Eur Respir J* 2020; **56**: 2001619.
- 84 Koehler P, Bassetti M, Chakrabarti A, et al. Defining and managing COVID-19-associated pulmonary aspergillosis: the 2020 ECMM/ISHAM consensus criteria for research and clinical guidance. *Lancet Infect Dis* 2021; **21**: e149–62.
- 85 Torrego A, Pajares V, Fernández-Arias C, Vera P, Mancebo J. Bronchoscopy in patients with COVID-19 with invasive mechanical ventilation: a single-center experience. *Am J Respir Crit Care Med* 2020; **202**: 284–87.
- 86 Patrucco F, Albera C, Bellocchia M, et al. SARS-CoV-2 detection on bronchoalveolar lavage: an Italian multicenter experience. *Respiration* 2020; **99**: 970–78.
- 87 Barberi C, Castelnovo E, Dipasquale A, et al. Bronchoalveolar lavage in suspected COVID-19 cases with a negative nasopharyngeal swab: a retrospective cross-sectional study in a high-impact Northern Italy area. *Intern Emerg Med* 2021; **16**: 1857–64.
- 88 Sharma J, Nasa P, Reddy KS, et al. Infection prevention and control for ICU during COVID-19 pandemic: position paper of the Indian Society of Critical Care Medicine. *Indian J Crit Care Med* 2020; **24** (suppl 5): S280–89.
- 89 Rawson TM, Moore LSP, Zhu N, et al. Bacterial and fungal coinfection in individuals with coronavirus: a rapid review to support COVID-19 antimicrobial prescribing. *Clin Infect Dis* 2020; **71**: 2459–68.
- 90 Langford BJ, So M, Raybardhan S, et al. Bacterial co-infection and secondary infection in patients with COVID-19: a living rapid review and meta-analysis. *Clin Microbiol Infect* 2020; **26**: 1622–29.
- 91 Lansbury L, Lim B, Baskaran V, Lim WS. Co-infections in people with COVID-19: a systematic review and meta-analysis. *J Infect* 2020; **81**: 266–75.
- 92 Vaughn VM, Gandhi T, Petty LA, et al. Empiric antibacterial therapy and community-onset bacterial co-infection in patients hospitalized with Coronavirus Disease 2019 (COVID-19): a multi-hospital cohort study. *Clin Infect Dis* 2021; **72**: e533–41.
- 93 Karami Z, Knoop BT, Dofferhoff ASM, et al. Few bacterial co-infections but frequent empiric antibiotic use in the early phase of hospitalized patients with COVID-19: results from a multicentre retrospective cohort study in The Netherlands. *Infect Dis (Lond)* 2021; **53**: 102–10.
- 94 Langford BJ, So M, Raybardhan S, et al. Antibiotic prescribing in patients with COVID-19: rapid review and meta-analysis. *Clin Microbiol Infect* 2021; **27**: 520–31.
- 95 Calderón-Parra J, Muiño-Miguez A, Bendala-Estrada AD, et al. Inappropriate antibiotic use in the COVID-19 era: factors associated with inappropriate prescribing and secondary complications. Analysis of the registry SEMI-COVID. *PLoS One* 2021; **16**: e0251340.
- 96 Rodríguez-Baño J, Rossolini GM, Schultsz C, et al. Key considerations on the potential impacts of the COVID-19 pandemic on antimicrobial resistance research and surveillance. *Trans R Soc Trop Med Hyg* 2021; **115**: 1122–29.
- 97 Wu S, Wang Y, Jin X, Tian J, Liu J, Mao Y. Environmental contamination by SARS-CoV-2 in a designated hospital for coronavirus disease 2019. *Am J Infect Control* 2020; **48**: 910–14.
- 98 WHO and UNICEF. Water, sanitation, hygiene, and waste management for SARS-CoV-2, the virus that causes COVID-19. Geneva: World Health Organization, 2020.
- 99 Sharafi SM, Ebrahimpour K, Nafez A. Environmental disinfection against COVID-19 in different areas of health care facilities: a review. *Rev Environ Health* 2020; published online Aug 26. <https://doi.org/10.1515/reveh-2020-0075>.
- 100 León Molina J, Abad-Corpa E. Disinfectants and antiseptics facing coronavirus: synthesis of evidence and recommendations. *Enferm Clin* 2021; **31**: S84–88.
- 101 Shimabukuro PMS, Duarte ML, Imoto AM, et al. Environmental cleaning to prevent COVID-19 infection. A rapid systematic review. *Sao Paulo Med J* 2020; **138**: 505–14.
- 102 Wang J, Lee YF, Zhou M. What is the best timing for health care workers infected with COVID-19 to return to work? *Am J Infect Control* 2020; **48**: 1128–29.