Journal Pre-proof

Controversies in airway management of COVID-19 patients: updated information and international expert consensus recommendations

Huafeng Wei, Bailin Jiang, Elizabeth C. Behringer, Ross Hofmeyr, Sheila N. Myatra, David T. Wong, Ellen O' Sullivan, Carin A. Hagberg, Barry McGuire, Paul Baker, Jane Li, Maksym Pylypenko, Wuhua Ma, Mingzhang Zuo, Nuzhet M. Senturk, Uwe Klein

PII: S0007-0912(20)30896-5

DOI: https://doi.org/10.1016/j.bja.2020.10.029

Reference: BJA 1472

To appear in: *British Journal of Anaesthesia*

Received Date: 14 October 2020

Revised Date: 28 October 2020

Accepted Date: 30 October 2020

Please cite this article as: Wei H, Jiang B, Behringer EC, Hofmeyr R, Myatra SN, Wong DT, Sullivan EO', Hagberg CA, McGuire B, Baker P, Li J, Pylypenko M, Ma W, Zuo M, Senturk NM, Klein U, Controversies in airway management of COVID-19 patients: updated information and international expert consensus recommendations, *British Journal of Anaesthesia*, https://doi.org/10.1016/j.bja.2020.10.029.

Controversies in airway management of COVID-19 patients: updated information and international expert consensus recommendations

Huafeng Wei[†, *, 1], Bailin Jiang[†, 1, 2], Elizabeth C. Behringer[3], Ross Hofmeyr[4], Sheila N Myatra[5], David T. Wong[6], Ellen O' Sullivan[7], Carin A. Hagberg[8], Barry McGuire[9], Paul Baker[10], Jane Li[11], Maksym Pylypenko[12], Wuhua Ma[13], Mingzhang Zuo[14], Nuzhet M. Senturk[15], Uwe Klein[16]

[1] Department of Anaesthesiology and Critical Care, University of Pennsylvania, Philadelphia, PA, USA
[2] Department of Anaesthesiology, Peking university people's hospital, Beijing, China
[3] Division of Cardiovascular Surgery & Critical Care, Kaiser Permanente Los Angeles Medical Center, Los Angeles, California, USA
[4] Department of Anaesthesia & Perioperative Medicine, University of Cape Town, and Groote Schuur Hospital, Cape Town, South Africa
[5] Department of Anesthesiology, Critical Care and Pain, Tata Memorial Hospital, Homi Bhabha National Institute, Mumbai, India
[6] Department of Anesthesia, Toronto Western Hospital, University Health Network, University of Toronto, Toronto, ON, Canada
[7] Department of Anaesthesia and Intensive Care Medicine, St James's Hospital, Dublin, Ireland
[8] Department of Anesthesiology and Perioperative Medicine, The University of Texas MD Anderson Cancer Center, Houston, TX, USA
[9] Department of Anaesthesia, Ninewells Hospital, Dundee, UK
[10] Department of Anaesthesia, Starship Children's Health, Auckland, New Zealand
[11] Department of Anaesthesia and Pain Medicine, Central Coast Local Health District, NSW, Australia
[12] Department of Anesthesiology and Intensive Care, Shupyk National Medical Academy of Postgraduate Education, Kyiv, Ukraine
[13] Department of Anesthesiology, the First Affiliated Hospital of Guangzhou University of Chinese Medicine, Guangzhou, China
[14] Department of Anaesthesiology, Beijing Hospital, National Center of Gerontology, Institute of Geriatric Medicine, Chinese Academy of Medical Science, Beijing, China
[15] Istanbul Universitesi, Istanbul Tıp Fakültesi, Anesteziyoloji AD, Istanbul,

Turkey
[16] Südharz-Klinikum Nordhausen, Nordhausen, Germany

*Corresponding author. E-mail: Huafeng.wei@pennmedicine.upenn.edu

† These authors contributed equally to this article.

Keywords: airway management, COVID-19, healthcare workers, high-flow nasal oxygen, infection, personal protective equipment

As knowledge and experience in the management of critically ill COVID-19 patients has increased with time, a panel of international experts convened and formulated consensus opinions regarding controversial topics in advanced airway management based on current literature. Here we summarize updated information as well as international expert opinion on several controversial topics concerning airway management in critically ill COVID-19 patients.

Personal protection equipment

Recommendations for the personal protective equipment (PPE) required during aerosol-generating procedures (AGPs), such as advanced airway management, are inconsistent amongst different countries and regions.[1-8] Two new studies report conflicting results, either supporting[9] or opposing[10] tracheal intubation and extubation as AGPs. Both studies were limited by small sample size, and used different definitions of AGPs and particle detection methods. Additional carefully designed studies are needed to clarify the risk of aerosolized viral spread during tracheal intubation and extubation. In the interim, it is prudent to continue to consider both as AGPs. Maximal interventions to safeguard healthcare workers from cross-infection with SARS-CoV-2 must be maintained until this question is adequately studied.

Studies from China have classified levels of PPE (Fig 1).[11] Level III has been reported to protect healthcare workers from cross infection during a variety of AGPs including tracheal intubation (Table 1),[11-14] high-flow nasal

oxygen (HFNO) usage and tracheal intubation using a flexible intubating endoscope in COVID-19 patients.[14] Level II PPE, often used in other countries and regions outside China[4, 5, 7], may not provide full protection from cross infection. Cross infection rates in healthcare workers range from 0% to 14·7% (Table 1).[15, 16] The primary difference between level II and III PPE is that level III includes use of a face shield, eye goggles, water-resistant gown, and hooded coverall. This assists in avoiding exposure of skin or eyes to air and potentially aerosolized viral particles (Fig 1). Table 2 summarizes the commonly used levels of PPE around the world and the reported cross infection rates in healthcare workers. Videolaryngoscopy is the recommended approach for tracheal intubation in COVID-19 patients in order to maximise first pass success rate and minimise exposure of healthcare workers during the procedure.[1, 12, 17] Awake tracheal intubation (ATI) has been performed successfully using flexible bronchoscopy. To date, cross infection of healthcare workers has not been reported during ATI. Therefore, ATI should be considered for management of the anticipated difficult airway, especially when tracheal intubation under general anaesthesia is considered unsafe.[13] Level III PPE should be used.

Expert consensus: It appears that the higher the level of PPE used, the better the protection against cross infection. However, adequate protection of healthcare workers is often limited by the availability of PPE during a world pandemic. It is recommended to use the highest level of PPE available in the

management of COVID-19 patients, especially during performance of high-risk AGPs such as tracheal intubation, extubation or tracheostomy.[1, 12, 18, 19] Fit testing and supervised donning and doffing of PPE remain critical steps in the avoidance of cross infection of healthcare workers. It is crucial to note that PPE must be a part of a comprehensive infection control strategy in order to be effective. Healthcare workers remain a precious resource in the fight against COVID-19.[20]

Use of high-flow nasal oxygen

Many guidelines initially prohibited or discouraged use of high-flow nasal oxygen (HFNO) in COVID-19 patients, based on the potential risks of aerosol generation and viral spread.[1] The extent of this risk remains unresolved.[21] Some studies support[22, 23] use of HFNO while others do not (Table 2).[24-26] Use of HFNO in critically ill COVID-19 patients with hypoxic respiratory insufficiency has been examined for its potential benefit as the mortality rate of mechanically ventilated patients remains high.[27] COVID-19 patients with pulmonary failure but normal lung compliance appear to respond favorably to HFNO treatment, but those patients with impaired lung compliance may not derive the same benefit.[28] A cohort study from the 2009 epidemic of respiratory failure due to Influenza A found that use of HFNO reduced the need for mechanical ventilation by 45%.[29] The future use of HFNO in COVID-19 patients will be based on its efficacy to diminish hypoxaemia, the need for

mechanical ventilatory support and mortality.

Use of appropriate PPE, as well as supervised donning and doffing, are critical in avoiding cross infection from any AGP. Other factors, such as negative pressure rooms, high air exchange rates through the ventilation system, the ventilation system itself, and use of an anteroom are additional important interventions to reduce the risks of cross infection. The use of HFNO for apnoeic oxygenation during laryngoscopy and tracheal intubation is recommended for selected COVID-19 patients at high risk of hypoxaemia.[14]

Another controversy associated with the use of HFNO is the concomitant use of a simple surgical mask as a means to minimise dispersion of aerosols in spontaneously breathing COVID-19 patients. A preliminary study using computational fluid dynamic simulation determined that addition of a surgical mask over a properly fitted HFNO device may be an effective option to reduce droplet deposition from exhaled gas flow.[30] A recent study of healthy volunteers evaluated aerosol production with HFNO and Noninvasive Positive Pressure Ventilation (NIPPV) compared with 6 L min^{-1} low-flow nasal cannula (LFNO).[31] HFNO and LFNO were studied with and without subjects wearing a type 1 surgical face mask. Aerosol size and mass were measured at two and six feet from the subject's nasopharynx. There was no significant difference in aerosol production between HFNO, NIPPV or LFNO. The use of a surgical mask over the HFNO device did not change aerosolized particle spread.[31] Further study is critical to confirm the safety and efficacy of the practice of

applying a mask over HFNO devices. Barotrauma is a risk when HFNO is delivered simultaneously with a tightly sealed face mask, such as an anaesthesia face mask, due to excessive delivered pressure so this combination should be avoided.[32]

Expert consensus: There is currently no convincing evidence that HFNO increases the risk of COVID-19 cross infection to healthcare workers. Well-designed prospective studies are needed to clarify the risk, if any, and to assess risk reducing interventions. It is recommended that use of HFNO in COVID-19 patients depends on the risk-benefit ratio determined by the clinician for each patient until additional information is available.

Early or late tracheal intubation

Recent studies[1, 2, 12, 33] have recommended early tracheal intubation to minimise the risk of cross infection of healthcare workers. Early tracheal intubation may obviate the need for urgent intubation and may lessen the severity of hypoxaemia and haemodynamic instability during induction of anaesthesia and tracheal intubation. Results of the combined use of noninvasive respiratory support and awake prone positioning,[34] particularly in patients with the Type L (high compliance) acute respiratory distress syndrome (ARDS) are encouraging.[28] A recent report showed a significant drop in the mortality rate of patients admitted to ICU with COVID-19. This is likely due to multiple factors, including increased clinical experience, rapidly developing

management strategies and therapeutics as well as increased use of noninvasive ventilatory support such as HFNO.[35] Use of HFNO may delay tracheal intubation and mechanical ventilation, as well as reduce the need for admission to ICU.[21, 36-38]

Expert consensus: This controversy regarding early *vs* late tracheal intubation is still evolving.[39] It is recommended that the appropriate time to intubate COVID-19 patients may be dependent on their individual pathology and pathophysiology, the acute trajectory of their illness in addition to their responsiveness to trials of noninvasive airway management.

Summary

Level III PPE appears to provide healthcare workers with maximum protection against cross infection by aerosolized SARS-CoV-2 viral particles. The highest level of PPE should be considered in the management of COVID-19 patients, especially during performance of AGPs. Global efforts should provide adequate levels of PPE for all healthcare workers during the pandemic as well as uniform application of environmental controls. Use of HFNO should be considered for management of acute respiratory failure and following tracheal extubation of COVID-19 patients as long as optimal environmental measures and protective PPE are available for healthcare workers. Noninvasive ventilation is encouraged as the first line approach before tracheal intubation and mechanical ventilation in critically ill COVID-19

patients with the aforementioned caveats, although further study of this approach is warranted.

Authors' contributions

Conception and writing of manuscript: All authors

Declaration of interests

HW is a consultant of Well Lead Medical Company, Guangzhou, Guangdong, China. PAB has received travel assistance and funding for research from Fisher and Paykel Healthcare.

Acknowledgements

We thank David Gabrielsen (Department of Anesthesiology and Critical Care, University of Pennsylvania, Philadelphia, PA, USA) for his assistance with preparing Figure 1.

References

managing the airway in patients with COVID-19: Guidelines from the Difficult Airway Society, the Association of Anaesthetists the Intensive Care Society, the Faculty of Intensive Care Medicine and the Royal College of Anaesthetists. *Anaesthesia* 2020; **75**: 785-99

2. Brewster DJ, Chrimes N, Do TB, Fraser K, Groombridge CJ. Consensus statement: Safe Airway Society principles of airway management and tracheal intubation specific to the COVID-19 adult patient group. *Med J Aust* 2020; **212**: 472-81

3. Zuo MZ, Huang YG, Ma WH, et al. Expert Recommendations for Tracheal Intubation in Critically ill Patients with Noval Coronavirus Disease 2019. *Chin Med Sci J* 2020; **35**: 105-9

4. US Centers for Disease Control and Prevention. Interim Infection Prevention and Control Recommendations for Healthcare Personnel During the Coronavirus Disease 2019 (COVID-19) Pandemic. Available from,

https://www.cdc.gov/coronavirus/2019-ncov/hcp/infection-control-recommendations.html.
[Accessed 8 September 2020].

5. World Health Organization. Rational use of personal protective equipment (PPE) for coronavirus disease (COVID-19): interim guidance, 19 March 2020. Available from, https://apps.who.int/iris/handle/10665/331498/WHO-2019-nCoV-IPCPPE_use-2020.2-eng.pdf.
[Accessed 8 September 2020].

6. Public Health England. COVID-19: infection prevention and control. Published January 10, 2020. update August 7, 2020. Available from, https://www.gov.uk/government/publications/wuhan-novel-coronavirus-infection-prevention-and-control.
[Accessed 8 September 2020].

7. European Centre for Disease Prevention and Control (ECDC). Personal protective equipment (PPE) needs in healthcare settings for the care of patients with suspected or confirmed novel coronavirus (2019-nCoV). Feb 7, 2020. Available from, https://www.ecdc.europa.eu/sites/default/files/documents/novel-coronavirus-personal-protective-equipment-needs-healthcare-settings.pdf.
[Accessed 8 September 2020].

8. Şentürk M, El Tahan MR, Szegedi LL, et al. Thoracic Anesthesia of Patients With Suspected or Confirmed 2019 Novel Coronavirus Infection: Preliminary Recommendations for Airway Management by the European Association of Cardiothoracic Anaesthesiology Thoracic Subspecialty Committee. *J Cardiothorac Vasc Anesth* 2020; **34**: 2315-27

9. Dhillon RS, Rowin WA, Humphries RS, et al. Aerosolisation during tracheal intubation and extubation in an operating theatre setting. *Anaesthesia* 2020. https://doi.org/10.1111/anae.15301. Advance Access Published October 12

10. Brown J, Gregson FKA, Shrimpton A, et al. A quantitative evaluation of aerosol generation during tracheal intubation and extubation. *Anaesthesia* 2020. https://doi.org/10.1111/anae.15292. Advance Access Published October 6

11. Liu Z, Wu Z, Zhao H, Zuo M. Personal protective equipment during tracheal intubation in patients with COVID-19 in China: a cross-sectional survey. *Br J Anaesth* 2020; **125**: e420-e2

12. 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-e37

13. Cai SJ, Wu LL, Chen DF, et al. [Analysis of bronchoscope-guided tracheal intubation in 12 cases with coronavirus disease 2019 under the personal protective equipment with positive pressure protective hood]. *Zhonghua Jie He He Hu Xi Za Zhi* 2020; **43**: 332-4

14. Wu CN, Xia LZ, Li KH, et al. High-flow nasal-oxygenation-assisted fibreoptic tracheal intubation in critically ill patients with COVID-19 pneumonia: a prospective randomised controlled trial. *Br J Anaesth* 2020; **125**: e166-e8

15. Feldman O, Meir M, Shavit D, Idelman R, Shavit I. Exposure to a Surrogate Measure of Contamination From Simulated Patients by Emergency Department Personnel Wearing Personal Protective Equipment. *JAMA* 2020; **323**: 2091-3

16. Cook TM. Risk to health from COVID-19 for anaesthetists and intensivists - a narrative review. *Anaesthesia* 2020. https://doi.org/10.1111/anae.15220. Advance Access Published July 17

17. Meng L, Qiu H, Wan L, et al. Intubation and Ventilation amid the COVID-19 Outbreak: Wuhan's

Experience. *Anesthesiology* 2020; **132**: 1317-32

18. Liu M, Cheng SZ, Xu KW, et al. Use of personal protective equipment against coronavirus disease 2019 by healthcare professionals in Wuhan, China: cross sectional study. *BMJ* 2020; **369**: m2195

19. Gosling AF, Bose S, Gomez E, et al. Perioperative Considerations for Tracheostomies in the Era of COVID-19. *Anesth Analg* 2020; **131**: 378-86

20. MURI ASSUNÇÃO. More than 1,000 U.S. health workers have died of COVID-19; many were racial minorities, immigrants. NEW YORK DAILY NEWS 2020. Available from, https://www.nydailynews.com/coronavirus/ny-coronavirus-health-workers-died-covid-racial-minorities-immigrants-20200826-xklqztcr5ngylg2bkk3phj237y-story.html.
[Accessed 8 September 2020].

21. Agarwal A, Basmaji J, Muttalib F, et al. High-flow nasal cannula for acute hypoxemic respiratory failure in patients with COVID-19: systematic reviews of effectiveness and its risks of aerosolization, dispersion, and infection transmission. *Can J Anaesth* 2020; **67**: 1217–48

22. Santarpia JL, Rivera DN, Herrera VL, et al. Aerosol and surface contamination of SARS-CoV-2 observed in quarantine and isolation care. *Sci Rep* 2020; **10**: 12732

23. Loh NW, Tan Y, Taculod J, et al. The impact of high-flow nasal cannula (HFNC) on coughing distance: implications on its use during the novel coronavirus disease outbreak. *Can J Anaesth* 2020; **67**: 893-4

24. Leung CCH, Joynt GM, Gomersall CD, et al. Comparison of high-flow nasal cannula versus oxygen face mask for environmental bacterial contamination in critically ill pneumonia patients: a randomized controlled crossover trial. *J Hosp Infect* 2019; **101**: 84-7

25. Hui DS, Chow BK, Lo T, et al. Exhaled air dispersion during high-flow nasal cannula therapy versus CPAP via different masks. *Eur Respir J* 2019; **53**: 1802339

26. 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

27. Bhatraju PK, Ghassemieh BJ, Nichols M, et al. Covid-19 in Critically Ill Patients in the Seattle Region - Case Series. *N Engl J Med* 2020; **382**: 2012-22

28. Gattinoni L, Chiumello D, Caironi P, et al. COVID-19 pneumonia: different respiratory treatments for different phenotypes? *Intensive Care Med* 2020; **46**: 1099-102

29. Rello J, Pérez M, Roca O, et al. High-flow nasal therapy in adults with severe acute respiratory infection: a cohort study in patients with 2009 influenza A/H1N1v. *J Crit Care* 2012; **27**: 434-9

30. Leonard S, Atwood CW, Jr., Walsh BK, et al. Preliminary Findings on Control of Dispersion of Aerosols and Droplets During High-Velocity Nasal Insufflation Therapy Using a Simple Surgical Mask: Implications for the High-Flow Nasal Cannula. *Chest* 2020; **158**: 1046–9

31. Miller DC, Beamer P, Billheimer D, et al. Aerosol Risk with Noninvasive Respiratory Support in Patients with COVID-19. *J Am Coll Emerg Physicians Open* 2020; **1**: 521–6

32. Fisher & Paykel Healthcare. Optiflow Thrive-Optiflow Oxygen Kit AA400, Optiflow Filtered Nasal Cannula AA001M. Product Information.

33. Brown CA, 3rd, Mosier JM, Carlson JN, Gibbs MA. Pragmatic recommendations for intubating critically ill patients with suspected COVID-19. *J Am Coll Emerg Physicians Open* 2020; **1**: 80–4

34. Coppo A, Bellani G, Winterton D, et al. Feasibility and physiological effects of prone positioning in non-intubated patients with acute respiratory failure due to COVID-19 (PRON-COVID): a prospective cohort study. *Lancet Respir Med* 2020; **8**: 765-74

35. Armstrong RA, Kane AD. Outcomes from intensive care in patients with COVID-19: a systematic

review and meta-analysis of observational studies. *Anaesthesia* 2020; **75**: 1340–9

36. Geng S, Mei Q, Zhu C, et al. High flow nasal cannula is a good treatment option for COVID-19. *Heart Lung* 2020; **49**: 444–4445

37. Gürün Kaya A, Öz M, Erol S, Çiftçi F, Çiledağ A, Kaya A. High flow nasal cannula in COVID-19: a literature review. *Tuberk Toraks* 2020; **68**: 168-74

38. Lagi F, Piccica M, Graziani L, et al. Early experience of an infectious and tropical diseases unit during the coronavirus disease (COVID-19) pandemic, Florence, Italy, February to March 2020. *Euro Surveill* 2020; **25**: 2000556

39. Hernandez-Romieu AC, Adelman MW, Hockstein MA, et al. Timing of Intubation and Mortality Among Critically Ill Coronavirus Disease 2019 Patients: A Single-Center Cohort Study. *Crit Care Med* 2020; **48**: e1045-53

40. Lai X, Wang M, Qin C, et al. Coronavirus Disease 2019 (COVID-2019) Infection Among Health Care Workers and Implications for Prevention Measures in a Tertiary Hospital in Wuhan, China. *JAMA network open* 2020; **3**: e209666

41. Wu Z, McGoogan JM. Characteristics of and Important Lessons From the Coronavirus Disease 2019 (COVID-19) Outbreak in China: Summary of a Report of 72 314 Cases From the Chinese Center for Disease Control and Prevention. *JAMA* 2020; **323**: 1239–42

42. Livingston E, Bucher K. Coronavirus Disease 2019 (COVID-19) in Italy. *JAMA* 2020; **323**: 1335

43. Li J, Fink JB, Ehrmann S. High-flow nasal cannula for COVID-19 patients: low risk of bio-aerosol dispersion. *Eur Respir J* 2020; **55**: 2000892

44. Anelli F, Leoni G, Monaco R, et al. Italian doctors call for protecting healthcare workers and boosting community surveillance during covid-19 outbreak. *BMJ* 2020; **368**: m1254

45. Treibel TA, Manisty C, Burton M, et al. COVID-19: PCR screening of asymptomatic health-care workers at London hospital. *Lancet* 2020; **395**: 1608-10

46. Sullivan EH, Gibson LE, Berra L, Chang MG. In-hospital airway management of COVID-19 patients. *Crit Care* 2020; **24**: 292

47. Morcuende M, Guglielminotti J, Landau R. Anesthesiologists' and intensive care providers' exposure to COVID-19 infection in a New York City academic center: a prospective cohort study assessing symptoms and COVID-19 antibody testing. *Anesth Analg* 2020; **131**: 669–76

48. Mendelson M, Bokolo L, Boutall A, et al. Clinical management of COVID-19: Experiences of the COVID-19 epidemic from Groote Schuur Hospital. *S Afr Med J* 2020; **110**: 968–72

49. 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. https://doi.org/10.1111/anae.15170. Advance Access Published June 9

50. Agarwal A, Basmaji J, Muttalib F, et al. High-flow nasal cannula for acute hypoxemic respiratory failure in patients with COVID-19: systematic reviews of effectiveness and its risks of aerosolization, dispersion, and infection transmission. *Can J Anaesth* 2020; **67**: 1217-48

Table 1. Healthcare workers cross infection rate at different levels of personal protective equipment

	Infection rate of HCWs following tracheal intubation	Overall Infection rate of HCWs	Proportion of HCWs in confirmed COVID-19 cases
China			
Lack of protection			
Meng et al[17]			29% (40 / 138)
Level I			
Lai et al[40]		1·4% (93 / 6574)	
Level II			
Lai et al[40]		0·5% (17 / 3110)	
Level III[3]			
Wu et al[14]	0% (0 / 6)		
Cai et al[13]	0% (0 / 9)		
Yao et al[12]	0% (0 / 52)		
Liu et al[18]	0% (0 / 420) [a]		
Level I-III			
Liu et al[11]	2% (11 / 554) [b]		
Wu et al[41]			3.8% (1716 / 44672)
Italy			
Level II[7]			
Livingston et al[42]			9% (2026 / 22512)
Li et al[43]			>8% (>1116 / 13882)

Anelli et al[44]		9% (4824 HCWs) [c]
UK		
Level II[6]		
Treibel et al[45]		11% (44 / 400) [d]
USA		
Level II[4]		
Sullivan et al[46]		14.7% (508 / 3466)
Morcuende et al[47]		12.1% (11 / 91)
South Africa		
Level II		
Mendelson et al[48]	0% (0/41)	
International (17 countries)		
Level II [5]		
El-Boghdadly et al[49]	10.7% (184/1718) [e]	

[a] Tracheal intubation and other aerosol generating procedures. [b] No infection in operators with Level III PPE. [c] Total cases were not reported. [d] Total infection rate among asymptomatic HCWs. [e] The rate listed is the incidence of laboratory‐confirmed COVID‐19 diagnosis or new symptoms requiring self‐isolation or hospitalization after a tracheal intubation episode. This study included intubation in known and suspected COVID-19 patients. HCW, healthcare worker; PPE, personal protective equipment.

Table 2 Studies on use of High Flow Nasal Oxygen (HFNO) and risks of viral spread

Authors	Type of study	Subject	Details
Restrict Use			
Santarpia et al[22]	Clinical observation	SARS-CoV-2	The highest concentrations of virus in air were recorded during oxygenation through a nasal cannula.
Loh et al[23]	Simulation study	SARS-CoV-2	HFNO increased the dispersion distance of cough-generated droplets
Support Use			
Leung et al[24]	Randomized controlled crossover trial	Gram-negative bacteria	HFNO was not associated with increased air or contact surface contamination by bacteria in ICU patients
Hui et al[25]	Simulation study	Respiratory virus	HFNO with good interface fitting was associated with limited exhaled air dispersion of virus
Tran et al[26]	Systematic review	SARS-CoV	HFNO didn't increase transmission risk significantly
Rello et al[29]	Cohort study	H1N1v	No secondary infections in healthcare workers, nor nosocomial pneumonia occurred during HFNO therapy
Miller et al[31]	Volunteer simulation study	Aerosol production	No significant difference in aerosol production between either HFNO and low-flow nasal cannula
Neutrality			
Agarwal et al[50]	Systematic review	SARS-CoV-2	Unknown effects of HFNO on risk of virus spreading

Figure Legends

Fig 1. Classification of personal protective equipment.[11, 12, 17]

Note an N95 mask respirator or surgical mask could be used inside the powered air purifying respirator (PAPR) hood to protect against potential self-contamination during doffing of personal protective equipment (PPE).

	 	 
Level I	**Level II** Left: face shield; Right: eye goggles	**Level III** Left: both eye goggles and face shield; Right: powered air purifying respirator (PAPR)
Surgical mask, gloves, regular gown, cap	Equipment in Level I, PLUS: N95 or equivalent (or higher) respirator, Shoe covers, face shield or eye goggles, water-resistant gown or hooded coverall. (Some skin or eye exposure to air)	Equipment in Level II, PLUS: Both eye goggles and face shield or a PAPR both water-resistant gown and hooded coverall. (No skin and eyes exposure to air)