

# Respiratory management in severe acute respiratory syndrome coronavirus 2 infection

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## Abstract

The severe acute respiratory syndrome coronavirus 2 pandemic is to date affecting more than a million of patients and is challenging healthcare professionals around the world. Coronavirus disease 2019 may present with a wide range of clinical spectrum and severity, including severe interstitial pneumonia with high prevalence of hypoxic respiratory failure requiring intensive care admission. There has been increasing sharing experience regarding the patient's clinical features over the last weeks which has underlined the need for general guidance on treatment strategies. We summarise the evidence existing in the literature of oxygen and positive pressure treatments in patients at different stages of respiratory failure and over the course of the disease, including environment and ethical issues related to the ongoing coronavirus disease 2019 infection.

## Keywords

Severe acute respiratory syndrome coronavirus 2, coronavirus disease 2019, respiratory failure, acute respiratory distress syndrome, mechanical ventilation, oxygen therapy

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## Introduction

The spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has already taken on pandemic proportions, affecting over 200 countries and up to 1 m people in a matter of weeks. The high reproduction number ( $R_0=2.8$ ) compared with other respiratory viruses causing pneumonia, the severity of coronavirus disease 2019 (COVID19), the high number of affected healthcare workers (HCWs) estimated at 1:6, and deaths in the absence of specific treatment or vaccine, bring into focus the tension between the best supportive patient care (i.e. adjunctive oxygenation and ventilation), and the risk of cross infection through aerosol generation.<sup>1,2</sup>

COVID19 has a wide spectrum of clinical severity, ranging from asymptomatic to critically ill and, ultimately, death.<sup>3,4</sup> Most of the fatal cases have occurred in patients with advanced age or underlying medical

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comorbidities.<sup>5,6</sup> A common and prominent complication of advanced COVID19 is acute hypoxaemic respiratory insufficiency or failure requiring oxygen and ventilation therapies.<sup>7,8</sup> The need for invasive ventilation via an endotracheal tube is common amid this outbreak.

This article aims to address the evidence base for current best guidance on respiratory management of SARS-CoV-2 in a practical manner. It draws on previous information for respiratory virus associated severe pneumonias, characterised by SARS-CoV-2, avian influenza A (H5N1) virus, and the 2009 pandemic influenza A (H1N1) virus. Observational data of the COVID19 pandemic from China and Italy are drawn upon, modelling studies of aerolization risk, and new international therapeutic guidelines.<sup>9</sup> This information is evolving and may change as new data comes to light.

## Respiratory failure

Viral pneumonia is usually diagnosed in patients with particular clinical features and consistent imaging (chest radiography and/or computer tomography) findings. The clinical features include a fever, a dry cough, breathlessness and chest pain (sometimes pleuritic), and hypoxia (Peripheral saturation, SpO<sub>2</sub> <92%).<sup>3,4</sup> Secondary bacterial infections may also cause similar features. Respiratory distress may ensue, characterised by an increase in respiratory rate (>25/min), use of accessory muscles of breathing, tracheal tug, intercostal recession or paradoxical movement of the chest and abdomen.

The prevalence of hypoxic respiratory failure in patients with COVID19 is around 19%.<sup>6</sup> From available Chinese data, approximately 14% of patients admitted to hospital required supplemental oxygen, and 5% required intensive care.<sup>3,6,8</sup> In one study of 52 patients admitted to intensive care unit (ICU) in Wuhan City Hospital, 67% had acute respiratory distress syndrome (ARDS). 63.5% of patients received high-flow nasal oxygen (HFNO), 42% received non-invasive ventilation (NIV) and 56% were mechanically ventilated, with a 28-day mortality exceeding 60%.<sup>7</sup>

A number of practical questions arise when considering respiratory support in COVID19: first, what is the role of oxygen therapy, HFNO or NIV (i.e. continuous positive airway pressure (CPAP) or bilevel positive airway pressure (BiPAP-NIV))? Second, which factors indicate therapeutic failure and when should appropriate step up to mechanical ventilation occur? Third, what are the risks of HFNO, CPAP, BiPAP-NIV, all considered aerosol (or droplet)-generating procedures (AGPs)? Fourth, where should such therapeutic interventions be managed from an infection control and logistic perspective. Fifth, do they have a role

in weaning from mechanical ventilation as a bridge to liberation and sustained recovery?

## Oxygen therapy, HFNO, NIV

There are understandable concerns regarding respirable aerosol spread (droplet size range <5µm) and larger droplet (>10µm) spread, as the mode of transmissible infection to HCWs by respiratory systems. The risks are influenced by the type of delivery device and its flow rates, oronasal interface and their fit, environmental factors (i.e. single room or not, negative pressure, personal protective equipment (PPE) and distance from the source) and patient characteristics, such as severity, lung compliance and coughing or sneezing.<sup>10</sup>

### Oxygen therapy

No studies of oxygen therapy and outcomes are available for COVID19. However, one report suggested 41% of all patients admitted to hospital, and 70% with severe disease manifestations, required supplemental oxygen.<sup>3</sup> In the context of acute illness, including ARDS, high oxygen targets >96% have been associated with poor outcomes, whilst hypoxia is also associated with worse outcomes.<sup>11,12</sup>

For patients with COVID19, supplemental oxygenation with a low flow system via nasal cannula is appropriate (i.e. up to 6 l/min). Higher flows of oxygen may be administered using a simple face mask, venturi face mask or nonrebreather mask (e.g. up to 10–20 l/min), but as flow increases, the risk of dispersion also increases, augmenting the contamination of the surrounding environment and HCWs.

Considering the concerns regarding oxygen supply limitations during a pandemic, and the absence of benefit beyond SpO<sub>2</sub> 96%, the recent surviving sepsis campaign (SSC) COVID19 guidelines recommend a target of SpO<sub>2</sub> between 92–96% (weak recommendation) and to avoid SpO<sub>2</sub><90% (strong recommendation).<sup>13</sup>

### NIV

NIV is widely utilised for acute respiratory failure, both hypoxaemic and hypercapnic, through a range of oronasal, full face and helmet interfaces. The evidence base for its varied uses have recently been published in a joint American Thoracic Society/European Respiratory Society (ATS/ERS) statement, summarising grade and recommendations, before the current COVID19 pandemic.<sup>14</sup> These recommendations may be less applicable to COVID19 patients, in whom acute hypoxaemic respiratory failure and ARDS are more common presentations.<sup>8</sup>

Theoretically, NIV can offload respiratory muscles, so decreasing the work of breathing, whilst maintaining

adequate oxygenation and minute ventilation. Indeed, a single centre RCT of helmet vs face mask NIV for ARDS, after an initial 8 h of NIV showed reduced intubation rates (18.2% vs 61.5%,  $p < 0.02$ ), and reduced 90-day mortality (31.4% vs 56.4%,  $p < 0.02$ ).<sup>15</sup> However, this has not been reproduced.

There are additional concerns over the use of NIV in respiratory pandemics such as COVID19: NIV may aggravate severe forms of lung injury as a result of injurious transpulmonary pressures and large tidal volumes (see further in this article), and may delay initiation of invasive mechanical ventilation, leading to emergency or more unstable intubations that can increase the risk of transmission to the healthcare team.<sup>16,17</sup>

NIV is also at high risk of aerosolization, and strategies have been described to contain the risk of virus spread, also according to a previous report on severe acute respiratory syndrome (SARS) infection.<sup>17</sup>

### HFNO

High-flow humidified oxygen delivered through nasal cannula at 30–60 l/min has been shown to be well tolerated, whilst providing potential benefits of oxygenation through matching delivery to inspiratory demand, carbon dioxide clearance by functional anatomical dead space reduction, positive end expiratory pressure (PEEP) effect (around 0.7–1 cm H<sub>2</sub>O per every 10 l/min), improved dynamic compliance and reduced work of breathing in acute hypoxaemic respiratory failure and in stable hypercapnic respiratory failure.<sup>18</sup> Even though the evidence on mortality and length of stay was not as strong, the reduction in the need for intubation (compared to conventional oxygen therapy) is an important finding, particularly from the perspective of pandemics such as COVID19, where resources such as critical care beds and ventilators may become limited.<sup>13</sup>

HFNO does not seem to confer an increased risk of transmission of disease. Exhaled air dispersion distance during HFNO (up to 60 l/min) and NIV (including CPAP up to 20 cm H<sub>2</sub>O) via different interfaces is restricted (< 65 cm), provided that there is a good mask interface fitting for the latter.<sup>19</sup> This is similar or better than for conventional oxygen through nasal cannulae up to 6 l/min. In view of the increased dispersion by coughing, it has been suggested that masks covering the patient's face over the HFNO cannulae be additionally considered, so long as rebreathing is prevented.

Given the evidence for a decreased risk of intubation with HFNO compared with NIV in acute hypoxaemic respiratory failure, and the potential greater risk of nosocomial infection of healthcare providers with NIV, HFNO may be recommended over NIV.<sup>13,20</sup>

Despite the potential benefits of HFNO, it is important to recognise when it is failing. In the patient with de novo acute respiratory failure (ARF), with or without comorbidities and an expectation of recovery without the need for intubation, there would be the desire to maintain HFNO (or NIV) as the bridge to recovery, if no rapid deterioration is apparent. However, retrospective evidence in those who failed HFNO suggests that a delay in intubation (> ~10–48 h) by persisting current support, in the face of worsening respiratory insufficiency (i.e. increased respiratory rate, hypoxia, respiratory acidosis) results in worse outcomes post-intubation (28-day mortality 39.2 vs 66.7%;  $p = 0.001$ ). Careful monitoring of patients for signs of deterioration, with a step-up/ceiling of the care plan should be adopted through local guidelines.

## Invasive mechanical ventilation

### Intubation

The decision to intubate can be obvious and require little deliberation, as for patients with cardiopulmonary arrest or a lost or jeopardised airway. However, in some patients with acute hypoxaemic respiratory failure due to COVID19, it may be challenging when deciding whether to proceed with intubation and invasive mechanical ventilation. In COVID19, more than ever, pre-warned is pre-armed. Intubation is a high-risk procedure: around 10% of patients in this setting develop severe hypoxaemia ( $SpO_2 < 80\%$ ) and approximately 2% experience cardiac arrest.<sup>21</sup>

The Chinese Society of Anesthesiology Task Force on Airway Management released a fast-track publication with the recommendation to proceed with endotracheal intubation for patients showing no improvement in respiratory distress, tachypnoea (respiratory rate greater than 30 per min), and poor oxygenation (partial pressure of oxygen [PaO<sub>2</sub>] to fraction of inspired oxygen [FiO<sub>2</sub>] ratio less than 150 mm Hg) after 2 h high-flow oxygen therapy or NIV.<sup>22</sup> These criteria should be regarded as empirical as there is no robust supporting evidence. Intubation and invasive mechanical ventilation should not be adversely delayed!

Aerosol-generating procedures carried the highest risks of SARS transmission to HCWs (Table 1).<sup>1,2</sup> Intubation, and the steps leading up to it, are some of the highest-risk moments for COVID19 spread to HCWs and other patients.<sup>22,23</sup> Droplet precautions will not be enough to protect against COVID19 spread during intubation. Droplet spread is caused by viral particles within small drops of bodily fluids.<sup>9</sup> Considering their larger size and mass, they fall with gravity within a couple of meters.<sup>24</sup> In one retrospective SARS study, not only the intubating doctor, but also

**Table 1.** Intubation in the age of coronavirus disease 2019 (COVID-19).

Use	Avoid
Upgrade N95 ventilator	Avoid bagging (when critical, use two endotracheal tube (ETT) PPE-hand seal, viral filter)
Wear fluid resistant gown, standard gloves, face shield	Avoid prolonged intubation attempt (use most qualified and quickest technique)
Use negative pressure room <sup>a</sup>	Avoid open circuit (viral filter or clamp on ETT if disconnected)
Use rapid sequence intubation (full dose paralytic)	Do not bring PPE outside the room
Use video laryngoscope	
Most experienced intubator	Do not allow non-critical staff in the room
Two single-use filters (PALL BB50T Breathing Circuit Filter, Pall Corp., USA) to be placed in the inhalation and exhalation breathing circuits	

PPE: personal protective equipment.

<sup>a</sup>When available.

the nurses assisting the intubating doctor were at higher risk of infection.<sup>25</sup> As such, limiting the components of intubation that can send aerosolised virus into the room should be a priority. The intubation attempt should be as quick as possible with a fully paralysed patient with the minimum safe number of people in the room.<sup>13</sup> Intubate with a 7.0–8.0 mm inner diameter (women) or 8.0–9.0 mm inner diameter tracheal tube. It is prudent to use video laryngoscopy rather than direct laryngoscopy for intubation. Videoscopes also allow assistants to visualise the airway so that they can better facilitate the procedure, they limit proximity to the airway compared to direct view (Table 1).<sup>13</sup> Clamp tube and pause ventilator for airway manoeuvres or disconnections.

A detailed description on airway management in COVID19 patients is described elsewhere.<sup>21</sup> Tracheal intubation of the patient with COVID19 is a high-risk procedure for staff and patient. Anticipate potential difficulties, do not hesitate to contact a senior anaesthetist.

Intubations should be performed in a room deemed suitable for airborne isolation (reverse-isolation negative pressure room with antechamber). Where this is not feasible, a portable High-efficiency particulate air (HEPA) filter should be used in the room wherever possible. A HEPA filter is a mechanical air filter, used for isolation where maximum reduction or removal of submicron particulate matter from air is required. HEPA filters have been demonstrated to reduce virus transmission in simulated settings.<sup>13</sup> Unfortunately, when critical care is expanded to areas outside of the ICU, airway management may take place in rooms with positive pressure (e.g. operating theatres) or those with reduced air exchange.

PPE should be left in the room and garments under gowns should not leave the department.<sup>26</sup>

**Technique.** Preparedness minimises the chance of cross-infection and improves the chance of smooth intubation. When a patient requires intubation for acute hypoxaemic respiratory failure, they have minimal to no respiratory reserve, and their compensatory mechanisms have already been exhausted. An experienced practitioner, instead of students or junior personnel, should be assigned to this job. Careful and efficient airway evaluation, whenever possible, should be performed ahead of intubation. Consider packing all portable supplies, needed or potentially needed, in one package ready for use.

**Pre-oxygenation.** Make sure the airway is patent. One hundred per cent FiO<sub>2</sub> administered with a non-rebreather bag valve mask for 3 min before tracheal intubation failed can be used.<sup>27</sup> We would not recommend using BiPAP for pre-oxygenation in patients who are not on BiPAP ventilation; however, BiPAP ventilation (use 100% FiO<sub>2</sub> to maximise oxygenation) should be continued if it is already in use. Consider manual positive pressure ventilation using a bag valve mask (two-hand seal) but only if pre-oxygenation fails to improve oxygenation.

**Rapid sequence intubation.** After satisfactory pre-oxygenation, modified rapid sequence induction is the recommended technique for induction. Ketamine, midazolam and etomidate can be used as induction agent. Rocuronium 1.2 mg/kg or succinylcholine 1 mg/kg is administered immediately after loss of consciousness. Fentanyl 50–100 mcg, sufentanil 10–20 mcg or remifentanyl 2.5 mcg/kg may be used to suppress laryngeal reflexes and optimise the intubation condition. The choice and dose of anaesthetics should be determined on a case-by-case basis. The patient's haemodynamic stability and severity of illness should be taken in

consideration. Vasoactive drugs should be readily available to treat extreme cardiovascular reactions. The goal is to have the patient intubated within 60 s after administration of muscle relaxants. The rationale behind modified rapid sequence induction in China is to shorten the period of potentially ineffective ventilation, in critically ill patients with minimal to no oxygen reserve due to COVID19.<sup>22</sup> Patient coughing during intubation can generate aerosols and should be avoided.<sup>9</sup> Because opioids have the potential to cause coughing, some operators give opioids after the accomplishment of satisfactory muscle relaxation.

### Extubation/tracheostomy

The same precautions should be considered during extubation. Measures to prevent patient agitation, coughing and bucking should be applied.

NIV and HFNO are comparable in reducing extubation failure, whilst an alternating combination of HFNO and NIV reduces first week post extubation-reintubation rates from 18.2% to 11.8% as compared with HFNO alone.<sup>28</sup> Whilst not specifically studied in pandemic situations, and with appropriate infection control measures in place, this could be a consideration in the higher risk group at the point of planned extubation.

During the COVID19 pandemic, and with pressure on ventilator capacity, the role of tracheostomy potentially earlier than usual, with weaning by NIV, so as to relieve intensive care ventilators for patients, is being considered. Due to it being a high risk AGP, surgical tracheostomy in a theatre setting, with negative pressure and full PPE is considered safer than the percutaneous technique.<sup>29</sup> Units with expertise in difficult weaning are best placed to drive and evaluate such a service through necessity.

### Ventilation management

The ventilatory management of these patients follows the same key principles of best practice as for classic ARDS aiming to avoid ventilator-lung injury (VILI), including the concepts of lung protective lung ventilation strategies.<sup>16,30</sup> The ARDS Network lung-protective ventilation guidelines recommend the use of use of low tidal volume (6 ml/kg per predicted body-weight) with a plateau airway pressure of less than 30 cm H<sub>2</sub>O, and increasing the respiratory rate to 35 breaths per min as needed (see Table 2). The tidal volume can be started at 8 ml/kg and then lowered with an ultimate goal of 6 ml/kg.<sup>30</sup> The precise tidal volume for an individual patient should be adjusted according to the patient's plateau pressure, selected PEEP, thoracoabdominal compliance, and breathing

**Table 2.** Calculation of ideal body weight (IBW).

Male	$IBW = 50.0 + 0.91 \times (\text{length in cm} - 152.4)$
Female	$IBW = 45.5 + 0.91 \times (\text{length in cm} - 152.4)$

effort.<sup>31</sup> Some clinicians believe that, as long as the plateau pressure can be maintained at less than or equal to 30 cm H<sub>2</sub>O, it may be safe to ventilate the patient with tidal volumes greater than 6 ml/kg predicted body weight.

If the hypoxaemia progresses to a PaO<sub>2</sub>:FiO<sub>2</sub> ratio of less than 100–150 mm Hg, the level of PEEP can be increased by 2–3 cm H<sub>2</sub>O every 15–30 min to improve oxygen saturation to 88–90%, with the goal of maintaining a plateau airway pressure of less than 30 cm H<sub>2</sub>O. At the bedside, PEEP titration can be performed using the pressure/volume curve however it requires patients to be deeply sedated and paralysed.

It is advantageous to have a driving pressure (plateau pressure minus PEEP) below 14 cm H<sub>2</sub>O via tidal volume and PEEP adjustments in patients who are not spontaneously breathing.<sup>32</sup> The respiratory rate should be set to maintain partial pressure of carbon dioxide (PaCO<sub>2</sub>) < 60 mm Hg (Table 3). The inspiration:expiration (I:E) is set 1:1 if expiratory flow reaches zero and no gas trapping occurs. If gas trapping, increase I:E up to 1:2.

Recruitment manoeuvres probably have little value, but moderate pressures of approximately 30 cm H<sub>2</sub>O for 20–30 s can be applied in the presence of a physician to monitor haemodynamics.<sup>33</sup>

Incremental PEEP titration recruitment manoeuvres, described as incremental increases in PEEP from 25 to 35 to 45 cm H<sub>2</sub>O for 1–2 min each, may be associated with increased mortality and should be avoided.<sup>13</sup> Recruitment manoeuvres are best combined with a higher PEEP strategy.

In mechanically ventilated adults with COVID19, severe ARDS and hypoxaemia despite optimising ventilation and other rescue strategies, a trial of inhaled nitric oxide as a rescue therapy may be considered; if no rapid improvement in oxygenation is observed, the treatment should be tapered off.<sup>13</sup>

Many patients with acute hypoxaemic respiratory failure due to COVID19 have breathing overdrive. Appropriate sedation and analgesia, such as dexmedetomidine, propofol and remifentanyl infusion, are warranted. The outcome evidence related to the use of muscle relaxants has been controversial.<sup>34,35</sup>

### Prone positioning

Prone positioning (also known as 'proning', 'prone manoeuvre' or 'prone ventilation') refers to mechanical ventilation with patients positioned in prone position in

**Table 3.** Respiratory targets.

1.	$pO_2 > 7$ kPa–52 mm Hg	(Ideally $> 8$ kPa–60 mm Hg)
2.	$pCO_2 < 8$ kPa–60 mm Hg	(Ideally $< 7$ kPa–52 mm Hg)
3.	pH $> 7.25/7.3$	
4.	SaO <sub>2</sub> 92–96%	

contrast to standard supine (flat or semi-recumbent) position. Proning should be considered early when adequate oxygenation cannot be achieved within ARDS Network lung protective ventilation parameters.

The use of the prone positioning was proposed over 30 years ago as a means to improve arterial oxygenation in patients with ARDS.<sup>36</sup> It has been shown that, independently of gas exchange, prone positioning may reduce the harm of mechanical ventilation, which is known to adversely impact patient survival.<sup>37–41</sup> Prone positioning theoretically makes ventilation more homogeneous by decreasing ventral alveolar distention and dorsal alveolar collapse.<sup>42</sup> In a small study of 52 patients, prone ventilation was used in 11.5% of COVID19 patients.<sup>7</sup> In contrast, given the potentially harmful effects, prone positioning should not be routinely used in patients with less severe ARDS.<sup>43</sup>

There are very few absolute contraindications to prone positioning, as spinal instability and unmonitored increased intracranial pressure. Other conditions should be identified as relative contraindication, as open abdominal wounds, multiple trauma with un-stabilised fracture, pregnancy, severe haemodynamic instability, and high dependency on airway and vascular access (e.g. extracorporeal membrane oxygenation support (ECMO)) (Table 4).

Prone positioning does not require any special equipment, and it can be safely performed manually by 3–5 specifically-trained healthcare personnel (Table 5). The optimal daily duration of prone positioning is still unknown. The final randomised controlled trials (RCTs) applied a longer time of prone positioning compared with early trials (i.e. 17–18 versus 7–9 h/day). The position may be varied in a paced rhythm of 1–2 h (slight rotations). New pressure areas on the front of the body should be carefully watched. Pressure on the eyes should be avoided. The optimal timing and weaning criteria from prone positioning remain undetermined.

## ECMO

The evidence supporting the use of ECMO vs conventional mechanical ventilation in severe ARDS is limited.<sup>44–46</sup> ECMO is a resource-intensive technique and should be restricted to specialised centres, and it remains an extremely limited resource. The risk of

**Table 4.** ‘Proning’ contraindications.

<p>Proning absolute contraindications:</p> <ul style="list-style-type: none"> <li>• Open abdomen</li> <li>• Unstable cervical spine</li> </ul> <p>Relative contraindications include:</p> <ul style="list-style-type: none"> <li>• Cardiovascular instability</li> <li>• Head injury with raised intra-cranial pressure (ICP)</li> <li>• Eye or facial injury</li> <li>• Thoraco-lumbar spinal injury</li> <li>• Pelvic fracture</li> <li>• Recent abdominal surgery</li> <li>• Gross ascites or obesity</li> <li>• Pregnancy in 2nd or 3rd trimester</li> <li>• Mechanical circulatory support</li> </ul>
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bleeding is an important consideration. Its use as a rescue therapy should be reserved for carefully selected COVID19 patients.<sup>47</sup>

Clinically veno-venous (VV) ECMO should be considered as a rescue therapy when  $PaO_2/FiO_2 < 80$  mm Hg for  $> 6$  h or  $PaO_2/FiO_2 < 50$  mm Hg for  $> 3$  h with severe respiratory acidosis (pH  $< 7.25$  with  $PaCO_2 \geq 60$  mm Hg) despite the use of neuromuscular blockade, recruitment manoeuvres, pronation, inhaled pulmonary vasodilators, optimised respiratory rate and plateau pressure.<sup>48</sup> VV ECMO can be considered if the patient is too haemodynamically unstable to be prone, proning is contra-indicated or to facilitate safe transport to an expert centre for ongoing management.

## Different respiratory treatment for different phenotypes?

Despite falling in most of the circumstances under the Berlin definition of ARDS, COVID19 pneumonitis seems a specific disease.<sup>49</sup> The same disease presents with impressive non-uniformity (Table 6). Patients may present quite differently from one another: normally breathing (‘silent’ hypoxaemia) or remarkably dyspnoeic; quite responsive to nitric oxide or not; deeply hypocapnic or normo/hypercapnic; and either responsive to prone position or not.

COVID19 pneumonitis is conceptualised as a continuum.<sup>50</sup> In the early stage, SARS-CoV-2 infection leads to sub-pleural interstitial oedema at the interface between lung structures (different elastic properties). Vasoplegia accounts for severe hypoxaemia. The near normal compliance explains why some patients present without dyspnoea as the patient inhales the volume he expects. The increase in minute volume (mainly in response to hypoxaemia) leads to a decrease in  $PaCO_2$ . A combination of increased lung permeability (inflammation) and negative inspiratory pressure (increased minute volume by increasing tidal volume)

**Table 5.** Pre-proning considerations.

- Ensure sufficient staff available with at least one senior doctor with intubation skills, three additional nurses or doctors.
- Assess pressure areas, ensure suitable mattress and consider extra padding.
- Eye care: clean and lubricate with simple ointment (e.g. Lubitears), then close with tape.
- Check grade of intubation, current length of ETT at teeth, and suitable ETT securing.
- Ensure deep sedation and adequate muscle relaxation when needed.
- Aspirate nasogastric tube (NGT) and pause feed while turning.
- Disconnect non-essential intravenous (IV) lines and luer-lock, for re-connection immediately following the turn (take great care with sterility).
- Ensure there is adequate length of IV tubing for essential infusions while turning.
- Remove electrocardiogram (ECG) electrodes from anterior chest wall and reposition on back/sides.
- If chest drains are present. Try to re-position chest drain sets without lifting above the patient.

**Table 6.** Coronavirus disease 2019 (COVID-19) pneumonitis is not created equal.

COVID19 pneumonia, type L	COVID19 pneumonia, type H
Early phase of disease	Late(r) phase of disease
Low elastance	High elastance
Low ventilation to perfusion (VA/Q)	High right-to-left shunt
Low lung weight (ground glass densities primarily located sub-pleural and along the lung fissures)	High lung weight
Low lung recruit ability	High lung recruit ability

**Table 7.** Kinds of 'filtering half masks' or 'filtering face pieces' (FFPs) (respirators that are entirely or substantially constructed of filtering material).

Class <sup>a</sup>	Filter penetration limit (at 95 l/min air flow)	Inward leakage
P1	Filters at least 80% of airborne particles	N/A
P2	Filters at least 94% of airborne particles	N/A
P3	Filters at least 99.95% of airborne particles	N/A
FFP1	Filters at least 80% of airborne particles	<22%
FFP2	Filters at least 94% of airborne particles	<8%
FFP3	Filters at least 99% of airborne particles	<2%

<sup>a</sup>European standard EN 149 test filter penetration with dry sodium chloride and paraffin oil aerosols after storing the filters at 70°C and -30°C for 24 h each. The standards include testing mechanical strength, breathing resistance and clogging. EN 149 tests the inward leakage between the mask and face, where 10 human subjects perform five exercises each and for eight individuals the average measured inward leakage must not exceed 22%, 8% and 2% respectively, as listed above.

results in interstitial lung oedema. This phenomenon has been recently recognised as the leading cause of patient-self inflicted lung injury (P-SILI).<sup>51</sup> With increasing oedema, the gas volume in the lungs decreases, the tidal volumes generated for a given inspiratory pressure decreases, and dyspnoea develops. The transition from type L to H may be due to both the evolution of COVID19 and injury attributable to high-stress ventilation.

Type L patients may respond to just an increase in FiO<sub>2</sub> (to reverse hypoxaemia) if not yet breathless, or HFNO/NIV if dyspnoea. High PEEP, in some patients, may decrease the pleural pressure swings and stop the vicious cycle that exacerbates lung injury. However, high PEEP in patients with normal compliance may have detrimental effects on haemodynamics. In any

case, noninvasive options are questionable, as they may be associated with high failure rates and delayed intubation, in a disease which typically lasts several weeks. Once intubated and deeply sedated, the type L patients, if hypercapnic, can be ventilated with volumes greater than 6 ml/kg (up to 8–9 ml/kg). as the high compliance results in tolerable strain without the risk of VILI. Prone positioning should be used only as a rescue manoeuvre, as the lung conditions are 'too good' for the prone position effectiveness, which is based on improved stress and strain redistribution. The PEEP should be reduced to 8–10 cm H<sub>2</sub>O, given that the recruit ability is low and the risk of haemodynamic failure increases at higher levels. An early intubation may avert the transition to type H phenotype. Type H patients, should be treated as severe

ARDS, including higher PEEP, if compatible with haemodynamics, prone positioning and extracorporeal support.<sup>50</sup>

## PPE

Protect yourself by wearing a fluid-resistant gown, two-layer gloves, an N95 respirator (FFP2 or 3), goggle, and face shield (Table 7).<sup>13</sup> Surgical masks (FFP1 are designed to block large particles, droplets and sprays, but are less effective in blocking small particle aerosols (< 5 µm), and will not prevent airborne transmission).<sup>52</sup> It is crucial to make sure the PPE is donned in the manner that will not interfere with procedures.

## Ethical issues

Beyond the daily practicalities of how, where and whether to provide oxygen adjuncts, HFNO, NIV or CPAP ventilation to patients with ARF, philosophical and moral questions around denying individuals such supportive care because of significant infection control concerns, continue to challenge frontline healthcare providers.

## Summary

Significant concerns regarding nosocomial infection of healthcare providers, availability of PPE, potential ventilator and oxygen supply shortages during the COVID19 pandemic, are necessitating risk benefit evaluations of conventional oxygen and respiratory support strategies for ARF.

## Conflict of interest

The authors declare that there is no conflict of interest.

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