Coronavirus disease 2019 (COVID-19): Airway management, anesthesia machine ventilation, and anesthetic care

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INTRODUCTION

The novel coronavirus disease 2019 (COVID-19 or nCoV) and other respiratory infectious agents pose risks for anesthesiologists and other clinicians in emergency medicine, critical care, pulmonary medicine, and infectious disease, as well as nurses and other health care personnel (eg, Certified Registered Nurse Anesthetists [CRNAs], respiratory therapists, emergency medical technicians). The pneumonia associated with this agent may lead to adult respiratory distress syndrome (ARDS) with profound hypoxemia and eventual multisystem organ failure.

This topic will address airway management of patients with suspected or confirmed diagnosis of COVID-19 infection, as well as management of short-term or long-term ventilation with an anesthesia machine and anesthetic care of these patients. Other topics discuss the obstetrical, medical, and critical care management of COVID-19 respiratory disease:

- (See "Neuraxial analgesia for labor and delivery (including instrumented delivery)", section on 'Patients with suspected or confirmed COVID-19'.)
- (See "Coronavirus disease 2019 (COVID-19): Critical care issues".)
- (See "Coronavirus disease 2019 (COVID-19): Management in adults".)
- (See "Coronavirus disease 2019 (COVID-19): Epidemiology, virology, clinical features, diagnosis, and prevention".)

KEY CONCEPTS

Key concepts for anesthesiologists and other anesthesia care team members (eg, Certified Registered Nurse Anesthetists [CRNAs], Certified Anesthesiologist Assistants [CAAs], anesthesia technicians) during care of patients with known or suspected COVID-19 or other respiratory infectious agents that may be transmitted via contact, droplet, or airborne modes include the following (refer to the Anesthesia Patient Safety Foundation [APSF]'s Perioperative Considerations for the 2019 Novel Coronavirus (COVID-19), the American Society of Anesthesiologists [ASA] Committee on Occupational Health's Coronavirus Information for Health Care Professionals (Clinical FAQs), the Centers For Disease Control and Prevent (CDC)'s personal protective equipment (PPE) sequence, and the ASA's joint position statement on The Use of Personal Protective Equipment by Anesthesia Professionals during the COVID-19 Pandemic) [1-14]:

- Prevention of infection of the anesthesia team members
- Prevention of contamination of anesthesia machine and equipment
- Management of the airway, typically with endotracheal intubation
- Management of short-term or long-term lung-protective ventilation in patients with viral pneumonia and/or adult respiratory distress syndrome (ARDS)

HAND HYGIENE AND USE OF PERSONAL PROTECTIVE EQUIPMENT (PPE) BY ANESTHESIA PERSONNEL

Frequent hand hygiene and proper donning and doffing of personal protective equipment (PPE) are essential to preventing transmission of COVID-19 or other respiratory infectious agents to health care workers [1,2]. For patients with suspected or confirmed infection with COVID-19, the following precautions for airway management are recommended by the American Society of Anesthesiologists (ASA) and the Anesthesia Patient Safety Foundation (APSF) [14,15]. These precautions are based on recommendations from the Centers for Disease Control (CDC), and previous experience with other infectious agents (eg, severe acute respiratory syndrome [SARS-CoV] or Middle Eastern respiratory syndrome [MERS-CoV] viruses) [1-9,11,13,16-20]. (See "Coronavirus disease 2019 (COVID-19): Epidemiology, virology, clinical features, diagnosis, and prevention" and "Coronaviruses".)

Before patient exposure — After handwashing, the clinician should don appropriate high-level PPE (figure 1). This includes an operating room cap, goggles (eye protection is mandated at all times), a fit-tested disposable N95 respirator mask (picture 1), ideally covered with a face shield, or a powered air-purifying respirator (PAPR) placed over the head (picture 2), a cover gown, and, if indicated, a beard cover (refer to the Centers for Disease Control and Prevention and the American Society of Anesthesiologists recommendations, and to Perioperative Considerations for the 2019 Novel Coronavirus (COVID-19) [13-15]. The clinician should also don gloves (using the double glove technique). Many institutions also require or provide protective footwear. High-level PPE reduces risk from infected droplets on the patient's skin and aerosol associated with aerosol generating procedures.

After patient exposure — Removal of PPE equipment should follow doffing process guidelines for high-risk level of exposure (figure 2). After removing gloves and other PPE, clinicians should avoid touching their own hair or face until they are able to perform fastidious hand hygiene.

If an anesthesia team member (or other healthcare worker) develops fever, cough, myalgias, or other systemic symptoms, they must inform the institutional occupational health department and report for testing and medical observation, which typically includes self-isolation at home.

MANAGEMENT OF PATIENT TRANSPORT

For patients undergoing procedures in an operating room (OR) setting, it is ideal to transport the patient directly to the designated OR, bypassing the holding area or pre-induction area. During transport, doctors and nurses should not touch environmental surfaces such as elevator buttons; this should be done by a security officer or another helper.

During transport, intubated patients should have a high-quality heat and moisture exchanging (HMEF) filter inserted between the self-inflating (Ambu) bag and the patient at all times. Nonintubated patients should continue wearing their surgical mask. In some cases (or in some institutions), it might be optimal to intubate the patient in their room (see below), prior to transport to the OR, especially if it is an intensive care unit (ICU). Some institutions use a demistifier tent for patient transport [21] .

PREVENTION OF CONTAMINATION OF ANESTHESIA MACHINES, EQUIPMENT, AND OPERATING ROOMS

Considerations for anesthesia machine and equipment — Preventing spread of infection via contamination of multiple components of the anesthesia machine (eg, breathing circuit, ventilator, surfaces) is critical, as noted in guidelines developed by the American Society of Anesthesiologists (ASA) and the Anesthesia Patient Safety Foundation (APSF; refer to the APSF's FAQ on anesthesia machine use, protection, and decontamination during the COVID-19 pandemic and the ASA Committee on Occupational Health's Coronavirus Information for Health Care Professionals (Clinical FAQs)) [4,15,22,23].

The anesthesia machine breathing circuit and its connection to the gas analyzer should be protected from becoming a vector of infection for subsequent patients via the anesthesia machine. The breathing circuit should contain two high-quality viral filters (eg, a heat and moisture exchange filter [HMEF] or high efficiency particulate air [HEPA] filter). One is placed at the patient end of the breathing circuit after the Y-piece connector (with placement of the sampling port on the side of the filter opposite to the patient) **and** a second filter is placed on the expiratory limb of the breathing circuit where it connects to the anesthesia machine. Thus, filtering is accomplished for the gas sampling line and the breathing circuit to and from the anesthesia machine. Furthermore, the "back up" filter on the expiratory limb not only serves to protect the machine from any particles passing through the primary filter, but it also significantly amplifies the effectiveness of the first filter.

There are four types of filtering devices:

- High quality pleated mechanical filters (eg, HEPA filters) with a viral filtration efficiency (VFE) no lower than 99.99 percent generally have the highest VFE even after exposure to humidity; and they also provide some heat and moisture exchange when placed at the airway. Notably, however, pleated filters have a minimum tidal volume requirement (typically 300 mL); thus, they may not be appropriate for pediatric patients <5 kg.
- Electrostatic filters, generally have a lower VFE; furthermore, VFE declines with exposure to humidity.
- HMEFs typically combine a heat and humidity exchanger and an electrostatic filter in one unit; thus, these are ideal for use in the breathing circuit after the Y-piece connector to provide protection to the anesthesia machine and gas analyzer.
- Other heat and humidity exchange (HME) devices without filters only provide heat and humidity exchange. Notably, these devices do **not** contain a filter, do **not** remove viral particles, and do **not** provide protection to the anesthesia machine.

Care must also be taken to prevent contamination of the external parts of the anesthesia machine, including the adjustable pressure-limiting (APL) valve and control knobs/buttons [1,23,24]. In some institutions, the anesthesia machine is covered with plastic (ie, a large plastic bag, used for storage in many institutions) to reduce the bioburden on "high touch" surfaces (picture 3) [10,25]. Plastic covers are also available for the patient monitor, computer keyboard, mouse, and touch screen in some institutions. However, the possibility of contamination of personnel, equipment, or the operating room (OR) during removal and disposal of such protective drapes is unknown; concerns are similar to those incurred by improper removal of personal protective equipment (PPE). (See 'Hand hygiene and use of personal protective equipment (PPE) by anesthesia personnel' above.)

Considerations for operating rooms — The ideal setting for patients with a highly contagious airborne or droplet disease is a negative pressure environment. In institutions with negative pressure ORs, those rooms are the preferred location for procedures on COVID-19 patients. However, most standard ORs are positive pressure environments that minimize risk of surgical site infection. One suggestion is to designate and maintain clean and dirty areas within the OR before beginning the case [23].

Decontamination issues — Ideally, both ultraviolet light (UV-C) and an Environmental Protection Agency (EPA)-approved hospital surface disinfectant are used for deep cleaning [1,23,24]. For improved routine and terminal cleaning, a top down approach involves spraying of all surfaces (including all computer keyboards and mice) with a quaternary ammonium compound, and then waiting the recommended drying time for that agent (typically one to three minutes) [23]. Further wiping is accomplished with a dry microfiber cloth, which should then be laundered. Wiping all surfaces and equipment again with the designated quaternary ammonium and alcohol surface disinfectant has been recommended to achieve adequate bioburden reduction in ORs since viral pathogens can survive on environmental surfaces for at least three days on a variety of materials commonly encountered in the OR (stainless steel, plastic) [23].

For the anesthesia machine, routine procedures per manufacturers' guidelines are used for cleaning (refer to FAQ on anesthesia machine use, protection, and decontamination during the COVID-19 pandemic and American Society of Anesthesiologists committee on Occupational Health: Coronavirus Information for Health Care Professionals (Clinical FAQs)) [4,22]. It is critically important that all high-touch surfaces on the anesthesia machine and anesthesia workstation are thoroughly cleaned and disinfected (eg, gas flow controls, vaporizer dials, the APL valve, shelves on the anesthesia machine) [1,23,24]. In addition, the anesthesia supply cart, IV stands, and fluid warmers must be included in the disinfection process. Reusable monitoring equipment also need to be thoroughly cleaned (eg, blood pressure cuffs pulse oximeter probes, electrocardiogram and twitch monitor devices and cables) [1].

The anesthesia breathing circuit, reservoir bag, mask, forced air warming blanket, and other disposable equipment are carefully discarded (ie, bagged for disposal as contaminated) [23].

Although the gas sampling tubing should be changed after use in a COVID-19 positive patient, the exterior of the water trap of the gas sampling line should be wiped with disinfectant wipes but does not need to be replaced between COVID-19 positive patients if appropriately placed high-quality HMEF filters were used as directed (see 'Considerations for anesthesia machine and equipment' above). Similarly, there is no evidence that the soda lime carbon dioxide (CO_2) absorber needs to be changed between COVID-19 positive patient cases (over and above normal depletion) since it is protected by the filters in the breathing circuit and is highly alkaline and likely viricidal.

The internal components of the anesthesia machine and breathing system do not need "terminal cleaning" if appropriately selected and placed high-quality filters were used as directed (see 'Considerations for anesthesia machine and equipment' above). In the event of overt or suspected contamination of the internal components of the anesthesia machine (eg, failure to use filters, incorrectly placed filters, or spillage or pulmonary edema fluid into the circuit), the specific manufacturer's recommendations will need to be followed. Some models of anesthesia machines require a prolonged period of decontamination according to manufacturer recommendations.

After the patient has left the OR, leave the room closed for one hour (refer to FAQ on anesthesia machine use, protection, and decontamination during the COVID-19 pandemic and American Society of Anesthesiologists committee on Occupational Health: Coronavirus Information for Health Care Professionals (Clinical FAQs)). The OR suite can then undergo deep terminal cleaning with an EPA-approved hospital disinfectant, and ideally with ultraviolet light, to reduce both viral and bacterial contamination [23]. During cleaning, technicians can don PPE routinely used for OR environmental cleaning and disinfection.

AIRWAY MANAGEMENT IN THE OPERATING ROOM

Nonintubated patients should continue wearing their surgical mask throughout their stay in the operating room (OR), as well as during transport.

Endotracheal intubation — For patients who required endotracheal intubation, aerosolized droplets can be splattered on the laryngoscopist's gown, gloves, face mask, eye shield, hair, neck, ears, and shoes during

laryngoscopy and endotracheal intubation, as well as during extubation [26]. Considerations to avoid or minimize contamination during intubation include [6-8,19,20,27,28]:

- Ensure that monitors are functioning properly (pulse oximetry [SpO_2], electrocardiography, blood pressure, waveform capnography), and optimize patient condition before induction (eg, small fluid bolus or administration of a vasopressor or inotrope if necessary). Also, aspirate the nasogastric tube if present. Ensure optimal patient positioning (eg, "sniffing position" with ramp, if necessary (figure 3)). (See "Airway management for induction of general anesthesia", section on 'Patient positioning'.)

- Only the most experienced anesthesia personnel should perform intubation in the OR. One other person should assist the clinician (eg, CRNA, anesthesia assistant, anesthesia technician, or circulating nurse). Non-anesthesia personnel (eg, surgeons, other nurses, trainees) should leave the OR during induction and intubation, if possible, to avoid unnecessary exposure. Once endotracheal intubation is completed, these personnel should not come back into the room immediately, but should allow a number of air exchanges in a positive pressure room before reentry.

- During laryngoscopy and intubation, double gloves will enable the clinician to shed the outer gloves to sheath the laryngoscope components to be decontaminated after the procedure, thereby minimizing subsequent environmental contamination.

- Oral or tracheal suction should be performed with a closed suction system after intubation (or extubation).

- For the COVID-19 patient with evidence of pneumonia and respiratory failure, preoxygenate for a minimum of five minutes with 100 percent oxygen. However, the patient should be instructed NOT to hyperventilate or take deep breaths during preoxygenation.

- Ideally, a rapid sequence induction and intubation (RSII) is performed with a nondepolarizing muscle relaxant such as rocuronium (1 mg/kg), but without cricoid pressure unless otherwise indicated. Avoid manual ventilation of the patient's lungs, if feasible. A laryngeal mask airway (LMA) may be inserted temporarily, if necessary. If mask ventilation is needed, the area around the patient's mouth and nose can be covered with wet gauze, and a two-person technique is used. These precautions help avoid aerosolization of contaminated droplets from the airway.

- Routine use of videolaryngoscopy is recommended to maximize the distance between the operator and the patient's oropharynx, as well as to minimize potential visual difficulties related to the use of a powered air-purifying respirator (PAPR) hood. Notably, post-procedure decontamination processes may differ depending on the specific type of videolarygnoscope used (eg, hand-held screen unit, disposable plastic sheathed laryngoscope with a remote screen mounted on a stand). Direct laryngoscopes should always be immediately available as well.

- Avoid awake fiberoptic intubation unless absolutely necessary due to abnormal airway anatomy, since there is a higher risk of coughing and subsequent aerosol generation with this technique, as well as the need to decontaminate the fiberoptic bronchoscope. However, for patients with potentially difficult airways, awake intubation may be necessary and should follow routine practice with adequate sedation, topical application of lidocaine as well as transcricothyroid injection in appropriate patients. If available, a

disposable fiberoptic bronchoscope should be used. (See "Flexible bronchoscopy in adults: Overview", section on 'Cleaning the bronchoscope'.)

- Once the endotracheal tube is passed through the cords to the proper depth (in adults, 19 to 22 cm measured at teeth), the cuff should be immediately inflated before hooking up the breathing circuit or any attempts to ventilate, and the clinician should ensure that there is no leak around the cuff. These precautions avoid inadvertent aerosol generation of contaminated droplets with the first and subsequent positive pressure breaths.

- For confirmation of proper endotracheal tube placement, end-tidal carbon dioxide ($EtCO_2$) confirmation, observation of bilateral chest expansion, and normal ventilator parameters (eg, peak pressure or pressure volume loops) are employed. Notably, hemoglobin saturation monitored with pulse oximetry is not always immediately increased after intubation as oxygen exchange may be significantly impaired by preexisting pneumonia or adult respiratory distress syndrome (ARDS). Avoid auscultation of the chest as this contaminates the clinician's face near the ear area during positioning of the stethoscope with dirty hands, and will bring the clinician's face closer to the patient's face. Furthermore, auscultation is not possible if a PAPR or other helmet device is placed over the head (picture 2), since the clinician's ears are inside the helmet. In addition, auscultation provides little additional information if videolaryngoscopy was used.

- Place all used airway equipment into a double zip-locked plastic bag. One suggestion is to place a wire basket lined with such a zip closure plastic bag on an IV pole close to the provider, for subsequent removal for decontamination [23].

- After induction of anesthesia, wipe down all equipment and surfaces with disinfection wipes that have anti-viral activity [23].

Tracheal extubation — In some cases (eg, after general anesthesia in patients with documented or suspected COVID-19-positive status), tracheal extubation is planned. (See 'Emergence and recovery' below.)

- High-level PPE is worn by clinicians performing extubation. Similar to endotracheal intubation, non-anesthesia personnel should leave the room during extubation, and should allow a number of air exchanges before reentry into a positive pressure room. (See 'Endotracheal intubation' above.)

- Some experts suggest administration of prophylactic lidocaine to reduce risk of coughing before tracheal extubation in a COVID-19-positive [5]. If general anesthesia was employed, prophylactic antiemetics should be administered near the end of the procedure to reduce risk of vomiting and consequent viral spread.

- Some experts suggest placement of wet gauze over the patients mouth and nose just prior to extubation if the patient starts to cough [7,18].

- After extubation, a surgical mask is placed over the patient's airway, with supplemental oxygen administered via a plastic mask applied over the surgical or N95 mask.

- Perform routine visual and manual maneuvers to ensure an adequate airway post extubation while wearing double gloves.

OFF-SITE ENDOTRACHEAL INTUBATION BY ANESTHESIA PERSONNEL

Considerations for anesthesiologists called to perform endotracheal intubation in locations outside the operating room (OR) are similar to those noted above, as summarized in the table (table 1) (see 'Airway management in the operating room' above). Additional considerations include prepackaging and advance preparation of necessary equipment. When feasible, availability of a second skilled clinician wearing personal protective equipment (PPE) is ideal, particularly for anticipated difficult airway. In some institutions, this clinician remains outside room, available to assist if necessary.

Notably, the risk of acquired infection in the clinician performing intubation is substantial. Evidence strongly suggests that even small lapses in proper use of PPE greatly increase this risk, particularly during emergency intubation and advanced cardiac life support (ACLS) scenarios [6].

VENTILATION MANAGEMENT

Ventilator settings — Most patients with COVID-19 requiring mechanical ventilation have acute respiratory distress syndrome (ARDS). Similar to other patients with ARDS, lung-protective ventilation with low tidal volumes, plateau pressure (Pplat) ≤30 cm H_2O, and application of positive end-expiratory pressure (PEEP) according to the strategy outlined in the table (table 2) are employed. (See "Coronavirus disease 2019 (COVID-19): Critical care issues", section on 'Ventilator management of acute respiratory distress syndrome'.)

Initial ventilator settings include:

- **Tidal volume** – Set tidal volume low, ideally at ≤6 mL/kg predicted body weight (PBW) (table 3 and table 4), typically using a volume-control mode setting and an inspiratory:expiratory (I:E) ratio of 1:2.
- **Respiratory rate** – Set initial respiratory rate (RR) to approximate adequate minute ventilation, typically between 14 to 22 breaths per minute (bpm), but not to exceed 35 bpm.
- **Plateau pressure** – Maintain Pplat ≤30 cm H_2O. Tidal volume and RR are adjusted to achieve this Pplat goal. If Pplat is >30 cm H_2O, decrease tidal volume by 1 mL/kg until Pplat is 25 to 30 cm H_2O or tidal volume is 6 mL/kg. If Pplat is <30 cm H_2O, but breath stacking (figure 4) or dyssynchrony is noted (see "Ventilator management strategies for adults with acute respiratory distress syndrome", section on 'Treat dyssynchrony'), then tidal volume may be increased in 1 mL/kg increments to 7 or 8 mL/kg so long as Pplat remains ≤30 cm H_2O.
- **Positive end-expiratory pressure** – Start with PEEP of at least 5 cm H_2O, then adjust according to the strategy outlined in the table to maintain adequate oxygenation and Pplat ≤30 cmH_2O (table 2). Anecdotal reports suggest that patients with the COVID-19 ARDS phenotype have relatively high lung compliance and are responsive to high levels of PEEP, such that maintenance of Pplat ≤30 cm H_2O is feasible. (See

"Coronavirus disease 2019 (COVID-19): Critical care issues", section on 'Ventilator management of acute respiratory distress syndrome'.)

- **Fraction of inspired oxygen** – Maintain the peripheral arterial oxygen saturation (SpO_2) at 92 to 96 percent. Incremental increases of either the fraction of inspired oxygen (FiO_2) and/or PEEP are used to achieve this oxygenation goal, while maintaining Pplat ≤30 cm H_2O, as noted in the table (table 2).

Long-term ventilation using anesthesia machines — Repurposing of anesthesia machines for longer-term use for days or weeks to ventilate COVID-19 patients with ARDS is unprecedented. Data are limited regarding the capability of the specific ventilators to reliably provide the potentially high levels of PEEP and minute ventilation required for patients with severe ARDS.

The American Society of Anesthesiologists (ASA) and the Anesthesia Patient Safety Foundation (APSF) have developed guidelines for anesthesia care team members regarding repurposing of anesthesia machines for longer-term ventilation (refer to the APSF/ASA Guidance on Purposing Anesthesia Machines as ICU Ventilators and Quick Reference: Setup and Monitoring Instructions – Anesthesia Machine as an ICU Ventilator) [29,30]. These professional societies recommend that anesthesia professionals be immediately available at all times to manage and monitor the anesthesia ventilator and assist with respiratory care. Limited data regarding duration of prolonged mechanical ventilation in COVID-19 patients with ARDS suggest that two or more weeks may be necessary. Collaboration with critical care teams throughout this period is clearly essential. (See "Coronavirus disease 2019 (COVID-19): Critical care issues", section on 'Ventilator management of acute respiratory distress syndrome'.)

Challenges with long-term anesthesia machine ventilation — Although newer anesthesia ventilators have sophisticated capabilities and incorporate multiple controlled and assisted ventilatory modes nearly identical to ventilators in the intensive care unit (ICU), there are several important technical issues that are unique to long-term ventilation with an anesthesia machine:

- The need for long-term humification and warming of inspired gases. This is best accomplished with a heat and moisture exchange filter (HMEF) placed at the endotracheal tube connection to the breathing circuit (after the Y-piece and after the gas sampling port) to filter out viral particles and ensure that adequate humidity is maintained in the lungs. As noted above, a second high quality filter is placed on the expiratory limb (see 'Considerations for anesthesia machine and equipment' above). These filters may need to be changed approximately every four hours to avoid filter obstruction due to moisture or secretions.

- The need to manage condensed water accumulation in the breathing circuit. Fresh gas flow (FGF) lower than minute ventilation will cause some water condensation within the breathing system. Excessive water can increase resistance to gas flow through the system and can interfere with sensors such as respiratory gas analyzers and flow sensors. Condensers and water traps can be added to some breathing systems to help manage this [29].

- The need to set FGF to equal minute ventilation (approximately 6 to 8 L/minute in adult patients), then monitor the circuit for excess humidity and increase FGF if moisture accumulation is a problem (see

'Monitoring long-term ventilation' below). The experience to date indicates that when an anesthesia machine is in long-term use as an ICU ventilator, reducing FGF leads to excessive humidity in the circuit, clogging of filters, and the need to change carbon dioxide (CO_2) absorbent frequently.

The ability to change FGF and alter the amount of exhaled gas rebreathing is a key feature distinguishing an anesthesia ventilator from an ICU ventilator. Generally, if the FGF exceeds minute ventilation, there is little to no rebreathing. However, as FGF is reduced, progressively more exhaled gas is rebreathed. Reduction in FGF substantially below minute ventilation is typically practiced during general anesthesia to conserve inhalation anesthetic agents. However, such reduction might not be appropriate for anesthesia machine use as an ICU ventilator due to the accumulation of condensed water in the breathing system. Furthermore, reduction in FGF is feasible only if there is an adequate supply of CO_2 absorbent that is not exhausted (see "Anesthesia machines: Prevention, diagnosis, and management of malfunctions", section on 'Carbon dioxide absorbent exhaustion or toxicity'). An anesthesia professional should be available to monitor degree of moisture accumulation, inspired and expired CO_2, and overall anesthesia machine function. (See 'Monitoring long-term ventilation' below.)

Reductions in FGF below minute ventilation are accomplished carefully in increments of 500 mL/minute, with vigilant monitoring for accumulation of excess moisture in the breathing circuit, and increases in FGF as necessary. Generally, it should be apparent in one to two hours if excess moisture is accumulating. Increasing FGF every four hours to exceed minute ventilation will also aid in drying the internal components of the breathing circuit. The ASA/APSF guidelines note that an alternative strategy is to increase total FGF to meet or exceed minute ventilation [29,30]. This option may be necessary in institutions that lack availability of CO_2 absorbent or anesthesia personnel to monitor anesthesia machine ventilation. However, the institutional supply of oxygen must be adequate to meet the needs of all ventilators in use at the same time within a hospital building. Also, the lack of humidity in the fresh gas may become a problem with such higher flows; thus, a HMEF will be necessary.

- Recognition that the inspired oxygen FiO_2 may be lower than the set FiO_2 because of rebreathing in an anesthesia machine circle system breathing circuit. The patient's inspired oxygen concentration will depend upon both the FGF and the amount of rebreathing, regardless of how the fresh gas oxygen concentration is set on individual anesthesia machines made by different manufacturers. Thus, inspired oxygen concentration must be monitored continuously. (See 'Monitoring long-term ventilation' below.)

- The potential need to adjust the scavenger system of the anesthesia machine to avoid high pressures due to backup of scavenged gas into the breathing system, with resultant high airway pressures and unintended PEEP.

  If the anesthesia machine is used outside of an operating room (OR), there may be no way to connect the scavenger system to a compatible waste anesthesia gas disposal outlet. In such cases, options include:

  - Connection of the scavenger system to suction in a location outside the OR if the connections are compatible, with adjustments of suction as necessary to accommodate increases in FGF
  - Disconnection of the scavenger system from the hoses coming from the breathing system and ventilator

- Removal of the scavenger reservoir bag (if it is a closed scavenger system)

- The need for periodic performance of an anesthesia machine self-test, approximately every 24 hours. This involves disconnecting the patient from the anesthesia machine ventilator (after temporarily clamping the endotracheal tube to prevent exhaled infected droplets from contaminating the immediate area), with hand ventilation of the patient using a self-inflating (Ambu) bag (ie, manual resuscitator), so that the anesthesia machine can be powered off and back on to perform its self-test.

  This maneuver may pose a hazard in patients who have low pulmonary compliance and require a high FiO_2 and high PEEP levels because a self-inflating bag may not provide adequate pulmonary support even if a PEEP valve is attached to the Ambu bag. In such cases, the ASA/APSF guidelines notes that the self-test may be performed at 72-hour intervals, or a transport ventilator may be employed (if available) while the self-test is being conducted (refer to APSF/ASA Guidance on Purposing Anesthesia Machines as ICU Ventilators and the ASA's Quick Reference: Setup and Monitoring Instructions – Anesthesia Machines as an ICU Ventilator) [29,30]. Strategies for supporting critically ill patients during this self-testing period have been developed by the APSF and ASA (refer to the APSF/ASA Procedure for Supporting Patients during the Anesthesia Machine Self-Test) [31].

- The need to periodically check the breathing circuit for possible kinking or compression due to the absence of an articulating arm to hold the breathing circuit up off the bed. ICU ventilators have an attached articulating arm component.

- Inhalation anesthetic agents are not usually administered for prolonged periods in critically ill patients because of their cardiovascular and other systemic effects (see "Inhalation anesthetic agents: Clinical effects and uses", section on 'Other clinical effects'), as well as the absence of safety data for long-term use. Also, scavenging of exhaled gas is required when inhalation anesthetics are delivered, and scavenging systems may not be readily available outside of the OR setting. Thus, the anesthetic vaporizers mounted on the anesthesia machine are typically removed to avoid accidental administration during use of a machine for long-term ventilation. However, some institutions may consider emergency use of low doses of a volatile inhalation anesthetic agent (isoflurane or sevoflurane) if there are inadequate supplies of the intravenous sedatives and analgesic agents commonly used in the ICU. APSF/ASA guidelines for such emergency use have been developed (refer to the APSF/ASA Guidance for Use of Volatile Anesthetic for Sedation of ICU Patients) [32]. (See 'Sedation of critically ill patients' below.)

Monitoring long-term ventilation — Goals for maintaining adequate oxygenation with maintenance of Pplat ≤30 cm H_2O in patients with COVID-19 ARDS are described above (see 'Ventilator settings' above). The ASA/APSF guidelines address monitoring requirements during use of anesthesia machines for long-term ventilation of COVID-19 patients (refer to APSF/ASA Guidance on Purposing Anesthesia Machines as ICU Ventilators and Quick Reference: Setup and Monitoring Instructions - Anesthesia Machine as an ICU Ventilator) [29,30].

Continuously monitored parameters (with preset alarms) include:

- Inspired oxygen concentration
- Inspired and expired carbon dioxide (CO_2)
- Inspiratory pressure
- Tidal volume
- Spirometry (ie, flow-volume and pressure-volume loops), if available

Intermittent inspection and maintenance of proper anesthesia machine and breathing circuit function include:

- Inspection of the breathing circuit hoses and water trap for excessive condensed water **every hour**, with periodic draining as necessary. This process typically requires a brief period of hand ventilation using a self-inflating (Ambu) bag. FGF should be increased if excess humidity and moisture accumulation are a problem.

- Inspection of the HMEF filters **every hour** for excessive humidity or secretions that may cause obstruction of gas flow. These filters are ideally changed every four hours. Impeded expiratory flow is detected by comparing expiratory flow tracings and flow-volume loops to baseline recordings. Impeded expiratory flow is detected by noting a decrease in peak expiratory flow or a prolongation of expiratory flow compared with baseline. Increased airway pressure is a late sign of obstruction because this pressure is sensed on the machine side of the HMEF filter that was placed at the endotracheal tube.

- Checks of Pplat during a 0.5 second inspiratory pause (see "Mechanical ventilation during anesthesia in adults", section on 'Plateau pressure'), at least once every four hours, and after each change in PEEP or tidal volume to ensure that it is ≤30 cm H_2O.

- Increases in FGF every four hours to exceed minute ventilation, which aids in drying the internal components of the breathing circuit. (See 'Challenges with long-term anesthesia machine ventilation' above.)

- Confirmation that there is no leak around the endotracheal tube cuff, typically manifesting as measured exhaled tidal volume that is lower than measured inhaled tidal volume, and a flow-volume loop that does not close.

- Confirmation that an anesthesia machine self-test was performed (in most patients, once every 24 hours).

Strategies for managing severe hypoxemia

Prone positioning — For patients with COVID-19 ARDS that fail standard low tidal volume ventilation, prone ventilation is the preferred next step. Prone positioning is optimal for patients with severe ARDS because it decreases ventral alveolar distention and dorsal alveolar collapse (figure 5). (See "Coronavirus disease 2019 (COVID-19): Critical care issues", section on 'Prone ventilation' and "Prone ventilation for adult patients with acute respiratory distress syndrome" and "Ventilator management strategies for adults with acute respiratory distress syndrome", section on 'Refractory patients'.)

It is critically important to adhere to appropriate precautions for prone positioning to avoid soft tissue injury (eg, nerve damage, pressure-induced injury or ulceration, or compartment syndrome). (See "Patient positioning for surgery and anesthesia in adults", section on 'Prone'.)

Other strategies — If prone positioning is inadequate for maintenance of adequate oxygenation, other ventilation strategies include:

- **High PEEP** – Maintain tidal volumes at 6 cc per kg (or down to 4 cc per kg with permissive hypercapnia) and use higher levels of PEEP (eg, 15 to 20 cm H_2O) as needed. (See "Coronavirus disease 2019 (COVID-19): Critical care issues", section on 'Ventilator management of acute respiratory distress syndrome' and "Ventilator management strategies for adults with acute respiratory distress syndrome", section on 'Further titration/increase in PEEP (high PEEP)'.)

- **Recruitment maneuvers** – Recruitment maneuvers may be performed; data supporting their use to address severe hypoxemia in non COVID-related ARDS are described separately. (See "Ventilator management strategies for adults with acute respiratory distress syndrome", section on 'Ventilator strategies to maximize alveolar recruitment'.)

- **Neuromuscular blocking agents (NMBAs)** – NMBAs may be reserved for patients with refractory hypoxemia or ventilator dyssynchrony. We do not favor their routine use in any patient with ARDS since data on outcomes are conflicting. (See "Acute respiratory distress syndrome: Supportive care and oxygenation in adults", section on 'Paralysis (neuromuscular blockade)' and "Neuromuscular blocking agents in critically ill patients: Use, agent selection, administration, and adverse effects".)

Sedation of critically ill patients — Sedation regimens for critically ill patients are discussed in separate topics:

- (See "Sedative-analgesic medications in critically ill adults: Selection, initiation, maintenance, and withdrawal".)
- (See "Sedative-analgesic medications in critically ill adults: Properties, dosage regimens, and adverse effects".)
- (See "Pain control in the critically ill adult patient".)

Notably, contamination of intravascular (IV) catheters during administration of sedatives or other agents is associated with increased mortality [23]. IV ports should be properly disinfected and capped [1,23]. Scrub all ports prior to injection and keep covered with disinfecting caps during and after administration of an IV agent. Keep syringes free of the contaminated environment, disinfected, and ready for use [1,23]. (See "Safety in the operating room", section on 'Infection risks for patients'.)

In institutions experiencing critical shortages of IV sedative-analgesic agents, emergency use of low doses of a volatile anesthetic agent may be considered, as noted above. (See 'Challenges with long-term anesthesia machine ventilation' above.)

Collaboration with critical care consultants — Collaboration and coordination with critical care consultants will be essential for care of COVID-19 patients regarding decisions for long-term ventilation of these patients using an anesthesia ventilator, and for management of comorbidities (eg, cardiovascular and renal complications, sepsis) [33-37]. (See "Coronavirus disease 2019 (COVID-19): Critical care issues".)

If hypotension develops, norepinephrine is employed as the first-line vasoactive agent to maintain mean arterial pressure 60 to 65 mmHg; vasopressin is added as a second-line agent if necessary (table 5) [37].

ANESTHETIC MANAGEMENT OF CONFIRMED COVID-19 POSITIVE PATIENTS

For COVID-19-positive patients who require an urgent or emergency surgical procedure or other intervention, performance of a minor procedure at the bedside is ideal. Some patients will require more complex or major procedure, and must be transported to the operating room (OR) or another location [7]. All precautions regarding donning and doffing personal protective equipment (PPE) are employed (figure 1 and figure 2), as well as management of transport to the procedural location, prevention of contamination of anesthesia machine and equipment, and management of the airway, as noted above:

- (See 'Management of patient transport' above.)
- (See 'Prevention of contamination of anesthesia machines, equipment, and operating rooms' above.)
- (See 'Airway management in the operating room' above.)

Choice of anesthetic technique — For the nonobstetric surgical patient with known COVID-19 infection and active symptoms (eg, cough, signs of pneumonia) or adult respiratory distress syndrome (ARDS), general endotracheal anesthesia with rapid sequence induction and intubation (RSII) is strongly preferred to minimize potential spread of aerosolized droplets. Patients with ARDS may already be intubated; ventilation is managed as described above (see 'Ventilator settings' above). For other patients, standard lung-protective intraoperative ventilation may be employed. (See "Mechanical ventilation during anesthesia in adults", section on 'Lung protective ventilation during anesthesia'.)

Some circumstances favor selection of regional anesthesia even for those with COVID-19 infection. For example, neuraxial anesthetic techniques remain the preferred option for labor and delivery, including obstetric patients presenting for cesarean delivery. (See "Neuraxial analgesia for labor and delivery (including instrumented delivery)", section on 'Patients with suspected or confirmed COVID-19'.)

General anesthesia

Anesthetic induction and maintenance — For hemodynamically stable COVID-19 patients, anesthetic induction agents for RSII may be selected according to usual considerations. Inhalation induction is avoided due to the potential for escape of aerosolized infected droplets around the mask. (See "Rapid sequence induction and intubation (RSII) for anesthesia", section on 'Induction agents' and 'Airway management in the operating room' above.)

For hemodynamically stable patients, maintenance techniques may be selected according to usual considerations. (See "Maintenance of general anesthesia: Overview".)

For COVID-19 patients in shock, induction and maintenance techniques are discussed in a separate topic. (See "Intraoperative management of shock in adults", section on 'General anesthesia'.)

Emergence and recovery — If extubation is planned after general anesthesia, prophylactic antiemetics should be administered at the end of the procedure to reduce risk of vomiting and consequent viral spread, and lidocaine may be administered to reduce risk of coughing. Similar to endotracheal intubation, non-anesthesia personnel should leave the OR during intubation, and should allow a number of air exchanges before reentry into a positive pressure room. If an upper body forced air warming device has been used, it is left in place during extubation so the plastic sheet covers the patient's head; subsequently, it is removed and bagged as a biohazard (see 'Decontamination issues' above). If no barrier is already in place, consider use of a plastic sheet to cover the patients face. Other precautions should be taken during tracheal extubation, as discussed above. (See 'Tracheal extubation' above.)

After extubation, avoid continuous positive airway pressure (CPAP), bilevel positive airway pressure (BiPAP), high-flow nasal cannula (HFNC) oxygen therapy, and nebulized medications since these may aerosolize infected droplets. Recovery after any procedure should occur while the patient remains in the OR, or after direct transport back to the intensive care unit (ICU), rather than in a post-anesthesia care unit (PACU) with COVID19-negative patients.

Local or regional anesthesia — For all non-intubated patients, a surgical mask or an N-95 (as available) with an overlying surgical mask (given the inability to perform a proper fit test) are required. Supplemental oxygen is administered via a plastic mask applied over the surgical or N95 mask.

ANESTHETIC MANAGEMENT OF SUSPECTED NONCONFIRMED COVID-19 PATIENTS

In many areas where COVID-19 is highly prevalent in the population (eg, major metropolitan areas performing only urgent or emergency surgical cases), any patient presenting for surgery may be COVID-19 positive, whether or not any symptoms are present.

Anesthesia care team members should don full personal protective equipment (PPE; (figure 1)) for any patient requiring general anesthesia, and for those receiving a regional anesthetic technique with a high likelihood of conversion to general anesthesia. Airway management with rapid sequence induction and intubation (RSII) using a videolaryngoscope is preferred, as described above. At the conclusion of the procedure, removal of PPE equipment should follow doffing process guidelines for high-risk level of exposure (figure 2), as described above. (See 'Hand hygiene and use of personal protective equipment (PPE) by anesthesia personnel' above and 'Airway management in the operating room' above.)

- **High-risk procedures –** For patients undergoing high-risk procedures in areas where COVID-19 is highly prevalent, not only the anesthesia care providers but all surgical team members should don full contact, droplet, and airborne PPE, as described above (see 'Hand hygiene and use of personal protective equipment (PPE) by anesthesia personnel' above), for the full duration of the case (figure 1).

  The following are examples of high-risk procedures for infection of anesthesia personnel as well as the surgical or interventional proceduralist and assistants, whether performed in the operating room (OR) or "off-site" locations:

- Any procedure on the airway, throat, mouth, or sinuses (eg, bronchoscopy, tracheostomy, glossectomy, laryngoscopy)
- Transesophageal echocardiography, endoscopy, or electroconvulsive therapy
- Cardiothoracic surgery
- Transsphenoidal (endonasal) approaches for neurosurgical procedures

- **Low-risk procedures without general anesthesia** – For patients undergoing low-risk procedures, standard PPE may be worn that includes a regular surgical mask (not necessarily an N95 respirator mask), gloves (not necessarily double gloves), a cap, a beard cover (if indicated), and, ideally, goggles. However the anesthesia provider(s) should consider donning full PPE if conversion to general anesthesia becomes more likely.

For prevention of anesthesia machine contamination, use of a high-quality viral filter (ie, a heat and moisture exchange filter [HMEF]) on the expiratory port of the breathing system is the minimum requirement for **all** patients in areas where COVID-19 is highly prevalent in the population.

SOCIETY GUIDELINE LINKS

Links to society and government-sponsored guidelines from selected countries and regions around the world are provided separately. (See "Society guideline links: Coronavirus disease 2019 (COVID-19) – International and government guidelines for general care" and "Society guideline links: Coronavirus disease 2019 (COVID-19) – Guidelines for specialty care".)

SUMMARY AND RECOMMENDATIONS

- Key concepts for anesthesia team members during care of patients with known or suspected novel coronavirus disease 2019 (COVID-19 or nCoV) include (see 'Key concepts' above):
  - Prevention of infection of the anesthesia team members
  - Prevention of contamination of anesthesia machine and equipment
  - Management of the airway, typically with endotracheal intubation
  - Management of short-term or long-term lung-protective ventilation in patients with viral pneumonia using an anesthesia machine ventilator

- Frequent hand hygiene and proper donning and doffing of personal protective equipment (PPE) are essential to preventing transmission of COVID-19 to health care workers (figure 1 and figure 2). (See 'Hand hygiene and use of personal protective equipment (PPE) by anesthesia personnel' above.)

- Transport of COVID-19 patients to an operating room (OR) is direct, bypassing any holding area. Clinicians should not touch environmental surfaces such as elevator buttons during transport; this is done by a nonclinical assistant. Intubated patients should have a high-quality viral filter (eg, a high efficiency particulate air [HEPA] filter, or a heat and moisture exchange filter [HMEF]) inserted between the self-inflating (Ambu) bag and the patient. Nonintubated patients should continue wearing their N95 surgical

mask. Recovery after any procedure should occur while the patient remains in the OR, or after direct transport back to the intensive care unit (ICU), rather than in a post-anesthesia care unit (PACU) with COVID-negative patients. (See 'Management of patient transport' above.)

- We agree with guidelines developed by the American Society of Anesthesiologists (ASA) and the Anesthesia Patient Safety Foundation (APSF) for preventing contamination of multiple components of the anesthesia machine including the breathing circuit, ventilator, and machine surfaces the APSF's FAQ on anesthesia machine use, protection, and decontamination during the COVID-19 pandemic and the ASA Committee on Occupational Health's Coronavirus Information for Health Care Professionals (Clinical FAQs)). (See 'Considerations for anesthesia machine and equipment' above.)

- Nonintubated patients should continue wearing their surgical mask throughout their stay in the OR, as well as during transport. Considerations during endotracheal intubation in the OR include (see 'Endotracheal intubation' above and 'Airway management in the operating room' above):

    - Performance of intubation by the most experienced anesthesia personnel. Non-anesthesia personnel should leave the OR during intubation, and should allow a number of air exchanges in a positive pressure room before reentry.

    - Double gloves enabling the clinician to shed the outer gloves to sheath the laryngoscope after intubation.

    - Oral or tracheal suction should be performed with a closed suction system after intubation (or extubation).

    - Preoxygenation for a minimum of five minutes with 100 percent oxygen. However, the patient should be instructed NOT to take deep breaths during preoxygenation.

    - Ideally, a rapid sequence induction and intubation (RSII) is performed with a nondepolarizing muscle relaxant such as rocuronium (1 mg/kg), but without cricoid pressure unless otherwise indicated. Avoid manual ventilation of the patient's lungs, if feasible. A laryngeal mask airway (LMA) may be inserted temporarily, if necessary. If mask ventilation is needed, the area around the patient's mouth and nose can be covered with wet gauze, and a two-person technique is used. These precautions help prevent aerosolization of contaminated droplets from the airway.

    - Routine use of videolaryngoscopy is recommended to maximize the distance between the operator and the patient's oropharynx, although direct laryngoscopes should always be immediately available as well. Avoid awake fiberoptic intubation if possible.

    - Once the endotracheal tube (ETT) is passed through the cords to the proper depth (in adults, 19 to 22 cm measured at teeth), the cuff is immediately inflated before hooking up the breathing circuit or any attempts to ventilate, and the clinician should ensure that there is no leak around the cuff. These precautions avoid inadvertent aerosol generation of contaminated droplets with the first and subsequent positive pressure breaths.

- Use end-tidal carbon dioxide (CO_2) confirmation, observation of bilateral chest expansion, and normal ventilator parameters (eg. peak pressure or pressure volume loops) to confirm proper ETT placement. Avoid routine auscultation of the chest since this brings the clinician's face closer to the patient's face than required.
- Sheath the laryngoscope immediately post-intubation (eg, within a glove after removal of the outer set of double gloves), and bag all used airway equipment for subsequent removal for decontamination.
- After intubation, wipe down all equipment and surfaces with Environmental Protection Agency (EPA)-approved hospital disinfectant, wipes that have anti-viral activity.

- Considerations during extubation include (see 'Tracheal extubation' above):
  - High-level PPE is worn by clinicians performing extubation. Similar to intubation, non-anesthesia personnel should leave the room during extubation, and should allow a number of air exchanges before re-entry into a positive pressure room before reentry.
  - Some experts suggest administration of prophylactic lidocaine to reduce risk of coughing before tracheal extubation in a COVID-19-positive patient. If general anesthesia was employed, prophylactic antiemetics should be administered near the end of the procedure to reduce risk of vomiting and consequent viral spread. (See 'Emergence and recovery' above.)
  - If an upper body forced air warming device has been used, leave this in place during extubation so the plastic sheet covers the patient's head, then remove it to bag as a biohazard. (See 'Decontamination issues' above.)
  - Some experts suggest placement of wet gauze over the patients mouth and nose just prior to extubation if the patient starts to cough.
  - After extubation, a surgical mask is placed over the patient's airway, with supplemental oxygen administered via a plastic mask applied over patient's mask.
  - Routine visual and manual maneuvers are performed to ensure an adequate airway post extubation while wearing double gloves.
- Considerations for anesthesiologists and other skilled clinicians called to perform endotracheal intubation in locations outside the OR are summarized in the table (table 1). (See 'Off-site endotracheal intubation by anesthesia personnel' above.)
- Most patients with COVID-19 requiring mechanical ventilation have acute respiratory distress syndrome (ARDS). We employ lung-protective ventilation with low tidal volumes, plateau pressure (Pplat) ≤30 cm H_2O, and application of positive end-expiratory pressure (PEEP) according to the strategy outlined in the table (table 2). (See 'Ventilator settings' above and "Coronavirus disease 2019 (COVID-19): Critical care issues", section on 'Ventilator management of acute respiratory distress syndrome'.)

- We agree with ASA/APSF guidelines regarding setup, management, and monitoring of anesthesia machines repurposed for longer-term ventilation of COVID-19 patients with ARDS (refer to the APSF/ASA Guidance on Purposing Anesthesia Machines as ICU Ventilators and Quick Reference: Setup and Monitoring Instructions – Anesthesia Machine as an ICU Ventilator). (See 'Long-term ventilation using anesthesia machines' above.)

- For the nonobstetric surgical patients with known COVID-19 infection and active symptoms (eg, cough, signs of pneumonia) or adult respiratory distress syndrome (ARDS), general endotracheal anesthesia is strongly preferred to minimize potential spread of aerosolized droplets. Neuraxial anesthetic techniques remain the preferred option for selected cases including obstetric patients presenting for cesarean delivery. (See 'Choice of anesthetic technique' above and "Neuraxial analgesia for labor and delivery (including instrumented delivery)", section on 'Patients with suspected or confirmed COVID-19'.)

- For patients with nonconfirmed COVID-19 infection who reside in areas where COVID-19 is highly prevalent in the population (eg, major metropolitan areas), any patient presenting for surgery may be COVID-19 positive, whether or not any symptoms are present. Anesthesia care team members should use full PPE (figure 1 and figure 2) for any patient requiring general anesthesia (or for those receiving a regional anesthetic technique with a high likelihood of conversion to a general anesthetic), and should manage the airway as described above. Other members of the surgical team should also use full PPE for high-risk procedures such as any procedure on the airway, throat, mouth, or sinuses (eg, bronchoscopy, tracheostomy, glossectomy, laryngoscopy), transesophageal echocardiography, endoscopy, cardiothoracic surgery, or transsphenoidal (endonasal) approaches for neurosurgical procedures. (See 'Anesthetic management of suspected nonconfirmed COVID-19 patients' above and 'Airway management in the operating room' above.)

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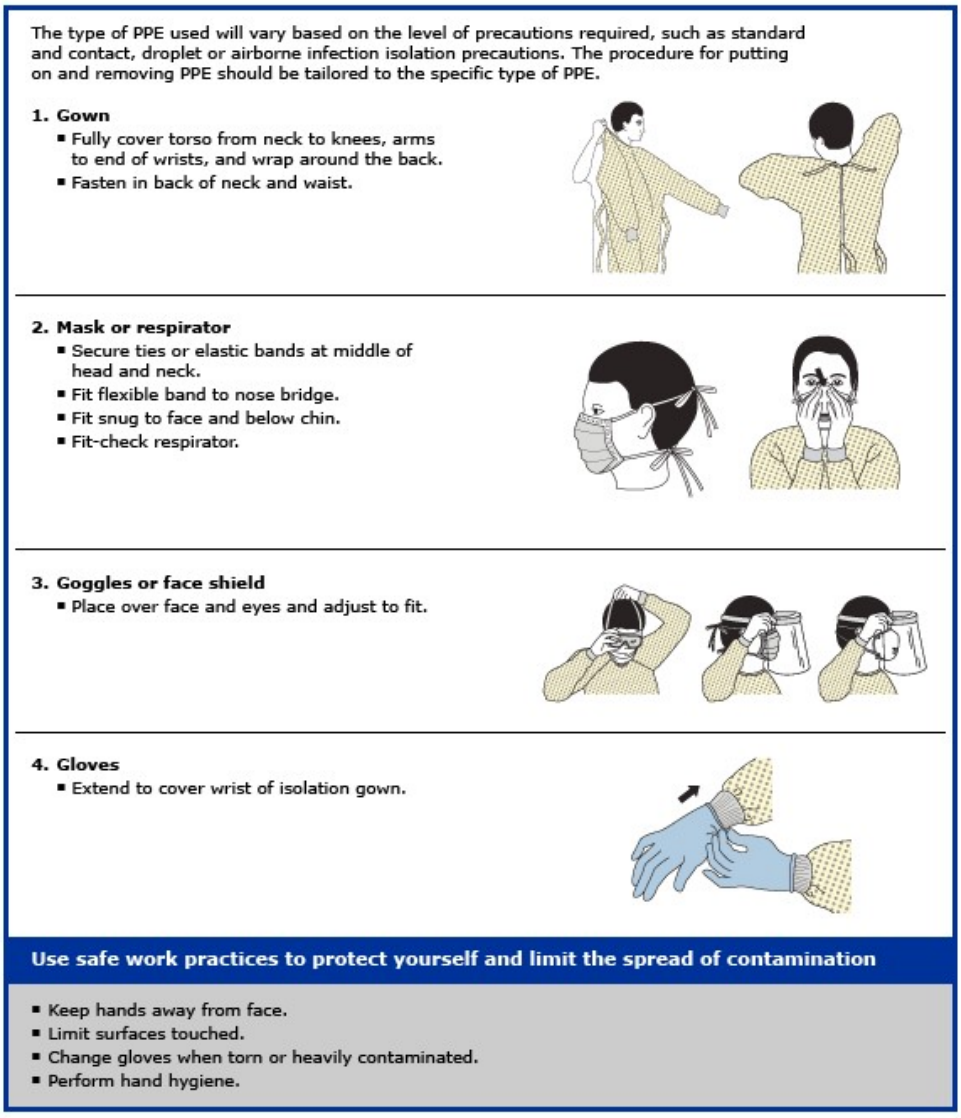
Topic 127481 Version 4.0

GRAPHICS

Putting on personal protective equipment



Sequence for putting on personal protective equipment.

Reproduced from: Centers for Disease Control and Prevention. Protecting Healthcare Personnel: Sequence for Donning and Removing Personal Protective Equipment. Available at: https://www.cdc.gov/hai/prevent/ppe.html (Accessed on March 20, 2020).

Graphic 127473 Version 1.0

Example of N95 mask

Reproduced from: N95 Respirators and Surgical Masks (Face Masks). U.S. Food & Drug Administration. Available at: https://www.fda.gov/medical-devices/personal-protective-equipment-infection-control/n95-respirators-and-surgical-masks-face-masks (Accessed on March 21, 2020).

Graphic 127476 Version 1.0

Endotracheal intubation while wearing powered air-purifying respirators

Two anesthesiologists using a videolaryngoscope for endotracheal intubation while wearing powered air-purifying respirators.

Graphic 127475 Version 1.0

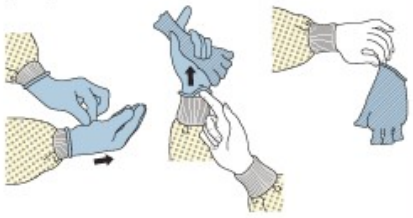
Taking off personal protective equipment

Example 1

There are a variety of ways to safely remove PPE without contaminating your clothing, skin, or mucous membranes with potentially infectious materials. Here is one example. **Remove all PPE before exiting the patient room** except a respirator, if worn. Remove the respirator **after** leaving the patient room and closing the door. Remove PPE in the following sequence:

1. Gloves

- Outside of gloves are contaminated!
- If your hands get contaminated during glove removal, immediately wash your hands or use an alcohol-based hand sanitizer.
- Using a gloved hand, grasp the palm area of the other gloved hand and peel off first glove.
- Hold removed glove in gloved hand.
- Slide fingers of ungloved hand under remaining glove at wrist and peel off second glove over first glove.
- Discard gloves in a waste container.



2. Goggles or face shield

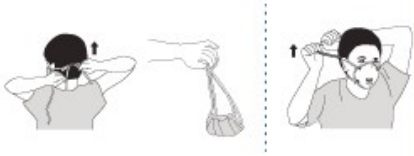
- Outside of goggles or face shield are contaminated!
- If your hands get contaminated during goggle or face shield removal, immediately wash your hands or use an alcohol-based hand sanitizer.
- Remove goggles or face shield from the back by lifting head band or ear pieces.
- If the item is reusable, place in designated receptacle for reprocessing. Otherwise, discard in a waste container.

3. Gown

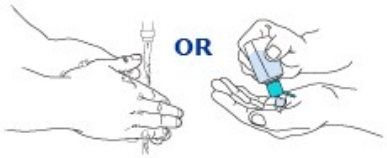
- Gown front and sleeves are contaminated!
- If your hands get contaminated during gown removal, immediately wash your hands or use an alcohol-based hand sanitizer.
- Unfasten gown ties, taking care that sleeves don't contact your body when reaching for ties.
- Pull gown away from neck and shoulders, touching inside of gown only.
- Turn gown inside out.
- Fold or roll into a bundle and discard in a waste container.

4. Mask or respirator

- Front of mask/respirator is contaminated. **DO NOT TOUCH!**
- If your hands get contaminated during mask/respirator removal, immediately wash your hands or use an alcohol-based hand sanitizer.
- Grasp bottom ties or elastics of the mask/respirator, then the ones at the top, and remove without touching the front.
- Discard in a waste container.



5. Wash hands or use an alcohol-based hand sanitizer immediately after removing all PPE



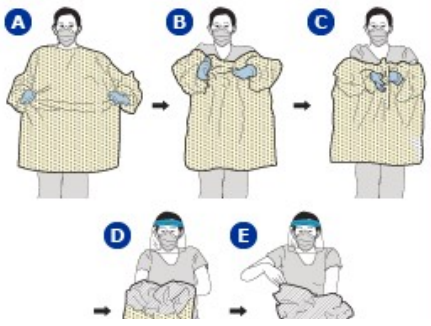
Perform hand hygiene between steps if hands become contaminated and immediately after removing all PPE

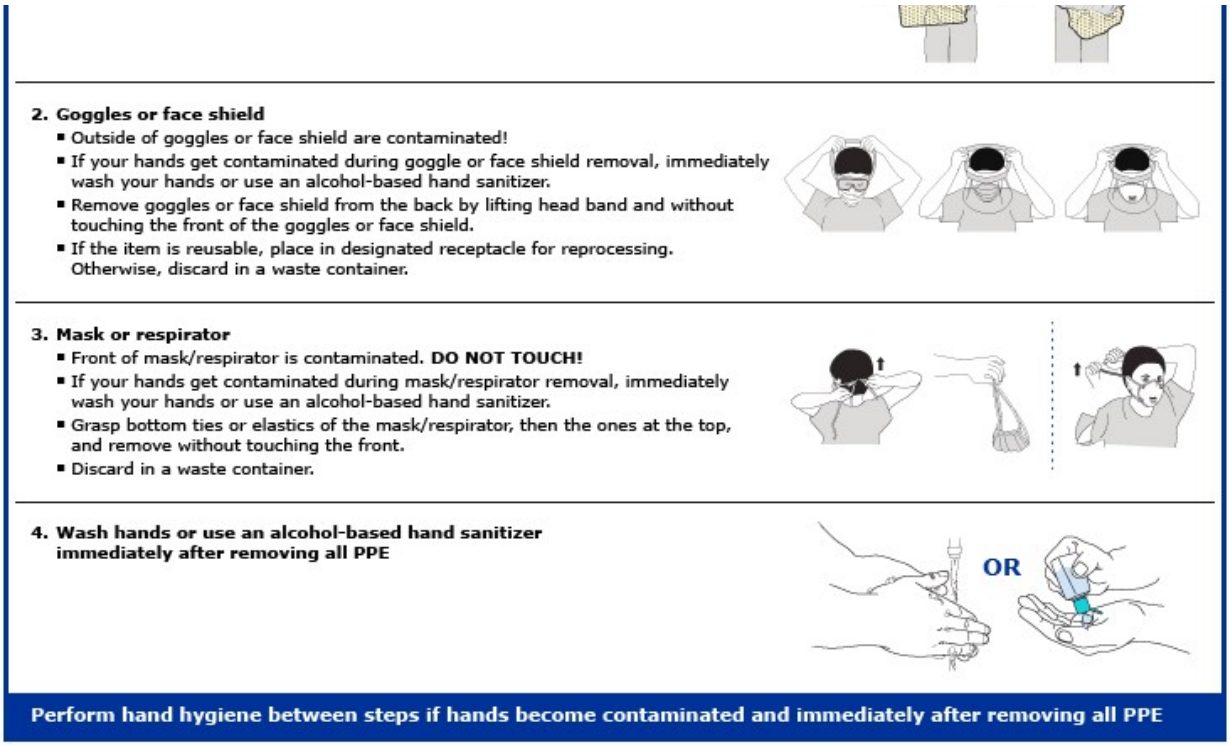
Example 2

Here is another way to safely remove PPE without contaminating your clothing, skin, or mucous membranes with potentially infectious materials. **Remove all PPE before exiting the patient room** except a respirator, if worn. Remove the respirator **after** leaving the patient room and closing the door. Remove PPE in the following sequence:

1. Gown and gloves

- Gown front and sleeves and the outside of gloves are contaminated!
- If your hands get contaminated during gown or glove removal, immediately wash your hands or use an alcohol-based hand sanitizer.
- Grasp the gown in the front and pull away from your body so that the ties break, touching outside of gown only with gloved hands.
- While removing the gown, fold or roll the gown inside-out into a bundle.
- As you are removing the gown, peel off your gloves at the same time, only touching the inside of the gloves and gown with your bare hands. Place the gown and gloves into a waste container.

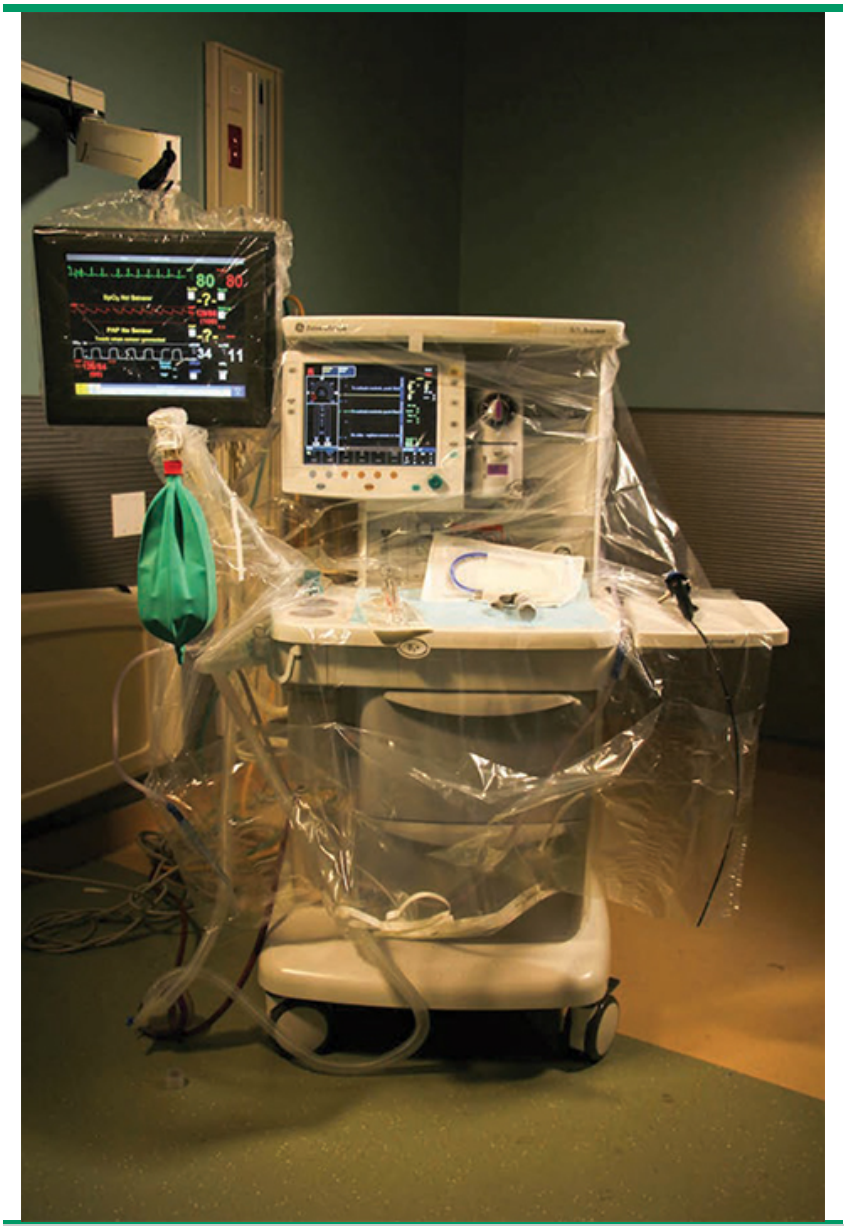




Reproduced from: Centers for Disease Control and Prevention. Protecting Healthcare Personnel: Sequence for Donning and Removing Personal Protective Equipment. Available at: https://www.cdc.gov/hai/prevent/ppe.html (Accessed on March 20, 2020).

Graphic 127474 Version 1.0

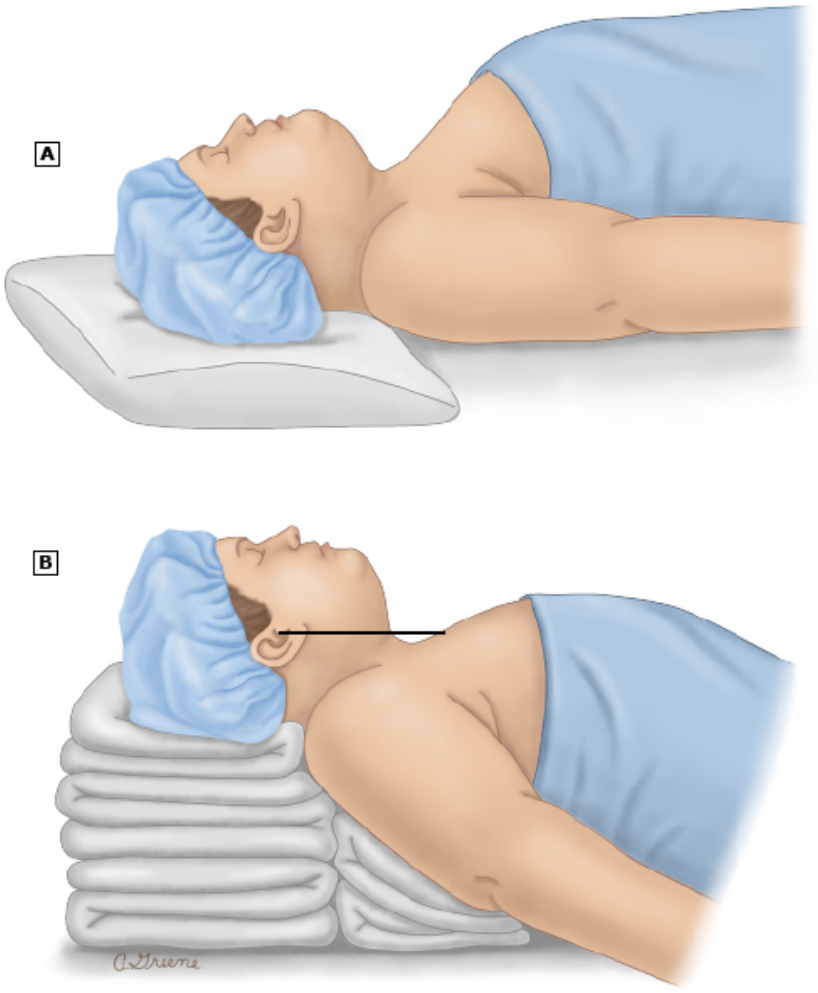
Anesthesia machine with plastic cover



An anesthesia machine is shown with a plastic cover.

Graphic 127494 Version 1.0

Ramp position illustration



In the ramp position, the patient's head and torso are elevated such that the external auditory meatus and the sternal notch are horizontally aligned (black line). This position allows for a better view of the glottis in obese patients and should be used unless there are contraindications (eg, possible cervical spine injury).

Graphic 95285 Version 4.0

Intubation of COVID-19 patients outside the OR: Guidelines and modifications[1-4]

Key principles	
▪ Maximize first-attempt success while keeping patients and providers safe. ▪ Prevent contamination and spread of virus. There is a high risk of aerosolization of virus during airway management.	
RSI steps (seven P's)	**Important actions and modifications**
Preparation	▪ Use checklist adapted for COVID-19 patients. Placing required airway equipment and medications in prepackaged bundles may be helpful.
	▪ Review airway plan as a team before entering room. RSI preferred whenever possible. Avoid awake intubation (cough during awake intubation increases viral spread).
	▪ Prepare all required equipment and draw up and label all medications (including induction agent, NMBA, vasopressor [eg, norepinephrine infusion], isotonic IVF) before entering intubation room.
	▪ Keep **all** nonessential equipment just outside room.
	▪ Have available all standard airway equipment plus: • Bag-mask **with HEPA filter** • Video laryngoscope with clear, disposable cover for the device • Ventilator and tubing **with in-line adaptors** (for suctioning and bronchoscopy) and **HEPA filters** • Waveform capnography if available • Smooth clamp for ETT
	▪ Use negative pressure room for intubation whenever possible.
	▪ Limit intubation team in room to 3 members: intubator, nurse, respiratory therapist.
	▪ If possible, second intubator wearing PPE should remain outside room to assist with anticipated difficult airway or as necessary.
	▪ Before entering room: • Perform hand hygiene. • Don PPE with proper technique and supervision. • Use N95 mask with face shield or PAPR. • Don double gloves, eye protection (airtight goggles if available), gown, and head cap. • Prepare marked bags for proper disposal/removal of clothing and equipment.
	▪ Avoid pretreatment with nebulizers if possible; use MDI instead.
Preoxygenation	▪ Preoxygenate patient for 3 to 5 minutes with 100% O_2 using low or moderate flow rates (10 to 15 L/minute) and NRB mask. Avoid BMV if at all possible. 5 minutes of preoxygenation preferred if circumstances permit.
	▪ If needed, can preoxygenate with modified NIV by using tightly fitting, non-vented mask connected to closed-circuit, dual-limb ventilator with HEPA filter. Use a full-face mask if available (reduces aerosolization). Mask must fit standard ventilator tubing. Continue NIV until patient apneic. Suspend ventilator before removing mask for intubation.
	▪ If patient remains hypoxic (SpO_2 <93%) using NRB mask and NIV with closed circuit not available, can use BMV with HEPA filter and PEEP valve. Hold mask tightly on patient's face using 2-hand thenar technique, increase oxygen flow rate as needed, and have patient breathe passively. Perform synchronized bag-assist ventilation only if required.
	▪ Avoid high-flow oxygenation methods (eg, flush rate) unless clinically required.
	▪ Avoid nasal cannula for oxygenation, including apneic oxygenation.
	▪ Upright posture or reverse Trendelenberg positioning improves preoxygenation.
	▪ Avoid BMV if at all possible; use HEPA filter if BMV must be performed.
	▪ If BMV necessary, 2-person thenar technique gives better seal and reduces aerosolization/contamination risk (provided entry of additional provider can be avoided). Provide BMV using low volumes and relatively high rates.

Pre-intubation optimization	▪ May give IV fluid bolus prior to giving RSI medications to patients who are volume depleted.
	▪ Avoid high-volume fluid resuscitation in COVID-19 patients at risk for ARDS.
	▪ Push-dose pressor may be needed for patients at high risk for hemodynamic decompensation (options include phenylephrine 100 micrograms IV or epinephrine 10 micrograms IV).*
	▪ Vasopressor (eg, norepinephrine) infusion may be needed for patients with hypotension or hemodynamic instability before or following administration of RSI medications.
Paralysis with induction	▪ Use high-dose NMBA: rocuronium 1.5 mg/kg IV or succinylcholine 2 mg/kg IV. Goal is rapid-onset apnea and elimination of cough.
Protection of patient and staff	▪ Refer to "Preparation" above and "Post-intubation management" below.
Placement (intubation)	▪ Use video laryngoscopy whenever possible.
	▪ Performed by experienced intubator.
	▪ Supraglottic airway preferred for rescue oxygenation and ventilation if needed (eg, intubation difficulty).
	▪ Ensure ETT is inserted 19 to 22 cm (measured at teeth); may reduce need for confirmation by chest radiograph.
Post-intubation management	▪ Inflate cuff immediately following ETT placement and **prior** to initiating PPV.
	▪ Confirm placement of the ETT. If a colorimeter or other removable $EtCO_2$ detector is used, clamp the ETT before removing the device.
	▪ After confirming ETT placement, clamp the ETT, connect the ventilator tubing, and then remove the clamp. HEPA filter between ETT and ventilator should be in place. Start mechanical ventilation. Secure the ETT.
	▪ Ventilator settings suitable for patient with ARDS are likely to be needed (assuming COVID-19-related respiratory illness is reason for intubation). ¶
	▪ Procedure bundles can reduce exposure. May choose to perform intubation and central venous catheter placement together and then obtain portable chest radiograph to assess both.
	▪ Limit ventilator disconnections. When disconnection required, clamp ETT first and disconnect at end-expiration.
	▪ Ideally, use ETT and ventilator with in-line adaptors for suctioning and bronchoscopy.
	▪ Ensure adequate sedation for patient care and safety and to avoid accidental extubation or disconnection of tubing.
	▪ Bag, transport, and clean all equipment as required.
	▪ Use proper PPE doffing, supervised by coach or other team member, including hand hygiene.

RSI: rapid sequence intubation; NMBA: neuromuscular blocking agent (paralytic medication); IVF: intravenous fluid; OR: operating room; ETT: endotracheal tube; PPE: personal protective equipment; PAPR: powered air-purifying respirator; MDI: metered dose inhaler; O_2: oxygen; BVM: bag-valve mask; NRB: nonrebreather; NIV: noninvasive ventilation; HEPA: high-efficiency particulate air; ARDS: acute respiratory distress syndrome; IV: intravenous; PPV: positive-pressure ventilation; $EtCO_2$: end-tidal carbon dioxide; SBP: systolic blood pressure; FiO_2: fraction of inspired oxygen.

* The use of a push-dose pressor is based on clinical judgement. It is most appropriate for patients with overt shock (eg, SBP <90 mmHg, SI >1) but may be useful in any hemodynamically unstable patient being intubated. For adults, options include phenylephrine 100 micrograms (50 to 200 micrograms) IV or epinephrine 10 micrograms (5 to 20 micrograms) IV, depending upon whether vasoconstriction alone or vasoconstriction and inotropic support is desired. Appropriate measures to improve hemodynamics as much as possible should be taken prior to intubation and push-dose pressor use.

¶ Initial ventilator management for adults with ARDS includes low tidal volume (6 mL/kg predicted body weight), volume-limited assist control mode, positive end-expiratory pressure (10 to 15 cm H_2O), and high FiO_2 (1.0). These settings are modified based on patient response. Refer to UpToDate topics discussing ventilator management in ARDS for details. For initial settings in children, please refer to UpToDate topics on initiating mechanical ventilation in children.

References:

1. *Wax RS, Christian MD. Practical recommendations for critical care and anesthesiology teams caring for novel coronavirus (2019-nCoV) patients. Can J Anaesth 2020.*

2. *Cook TM, El-Boghdadly K, McGuire B, et al. Consensus guidelines for 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.*
3. *Mason J, Herbert M. Novel Coronavirus 2019 (COVID-19). Available at: www.emrap.org/corependium/chapter/rec906m1mD6SRH9np/Novel-Coronavirus-2019-COVID-19?MainSearch=%22covid%22&SearchType=%22text%22 (Accessed on March 28, 2020).*
4. *Weingart S. COVID Airway Management Thoughts. Available at: https://emcrit.org/emcrit/covid-airway-management/ (Accessed on March 28, 2020).*

Graphic 127516 Version 11.0

Titration of PEEP

Higher PEEP/lower FiO_2																	
Step:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
FiO_2	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.7	0.8	0.8	0.9	1.0	1.0
PEEP	5	5	8	10	12	14	16	16	18	20	20	20	20	22	22	22	24

PEEP: positive end-expiratory pressure; FiO_2: fraction of inspired oxygen.

Adapted from:

1. *Brower RG, Lanken PN, MacIntyre N, et al. Higher versus lower positive end-expiratory pressures in patients with the acute respiratory distress syndrome. NEJM 2004; 351:327.*
2. *Meade MO, Cook DJ, Guyatt GH. Ventilation strategy using low tidal volumes, recruitment maneuvers, and high positive end-expiratory pressure for acute lung injury and acute respiratory distress syndrome: a randomized controlled trial. JAMA 2008; 299:637.*

Graphic 118834 Version 1.0

Predicted body weight and tidal volume for men

Height			PBW	Tidal volume				
Feet/inches	Inches	Centimeters	kg	4 mL/kg	5 mL/kg	6 mL/kg	7 mL/kg	8 mL/kg
4' 0"	48	122	22.4	90	112	134	157	179
4' 1"	49	124	24.7	99	124	148	173	198
4' 2"	50	127	27	108	135	162	189	216
4' 3"	51	130	29.3	117	147	176	205	234
4' 4"	52	132	31.6	126	158	190	221	253
4' 5"	53	135	33.9	136	170	203	237	271
4' 6"	54	137	36.2	145	181	217	253	290
4' 7"	55	140	38.5	154	193	231	270	308
4' 8"	56	142	40.8	163	204	245	286	326
4' 9"	57	145	43.1	172	216	259	302	345
4' 10"	58	147	45.4	182	227	272	318	363
4' 11"	59	150	47.7	191	239	286	334	382
5' 0"	60	152	50	200	250	300	350	400
5' 1"	61	155	52.3	209	262	314	366	418
5' 2"	62	157	54.6	218	273	328	382	437
5' 3"	63	160	56.9	228	285	341	398	455
5' 4"	64	163	59.2	237	296	355	414	474
5' 5"	65	165	61.5	246	308	369	431	492
5' 6"	66	168	63.8	255	319	383	447	510
5' 7"	67	170	66.1	264	331	397	463	529
5' 8"	68	173	68.4	274	342	410	479	547
5' 9"	69	175	70.7	283	354	424	495	566
5' 10"	70	178	73	292	365	438	511	584
5' 11"	71	180	75.3	301	377	452	527	602
6' 0"	72	183	77.6	310	388	466	543	621
6' 1"	73	185	79.9	320	400	479	559	639
6' 2"	74	188	82.2	329	411	493	575	658
6' 3"	75	190	84.5	338	423	507	592	676
6' 4"	76	193	86.8	347	434	521	608	694
6' 5"	77	196	89.1	356	446	535	624	713
6' 6"	78	198	91.4	366	457	548	640	731
6' 7"	79	201	93.7	375	469	562	656	750
6' 8"	80	203	96	384	480	576	672	768
6' 9"	81	206	98.3	393	492	590	688	786
6' 10"	82	208	100.6	402	503	604	704	805
6' 11"	83	211	102.9	412	515	617	720	823
7' 0"	84	213	105.2	421	526	631	736	842

PBW: predicted body weight.

Reproduced from: NHLBI ARDS Network. Available at: http://www.ardsnet.org/ (Accessed on November 20, 2012).

Graphic 87507 Version 6.0

Predicted body weight and tidal volume for women

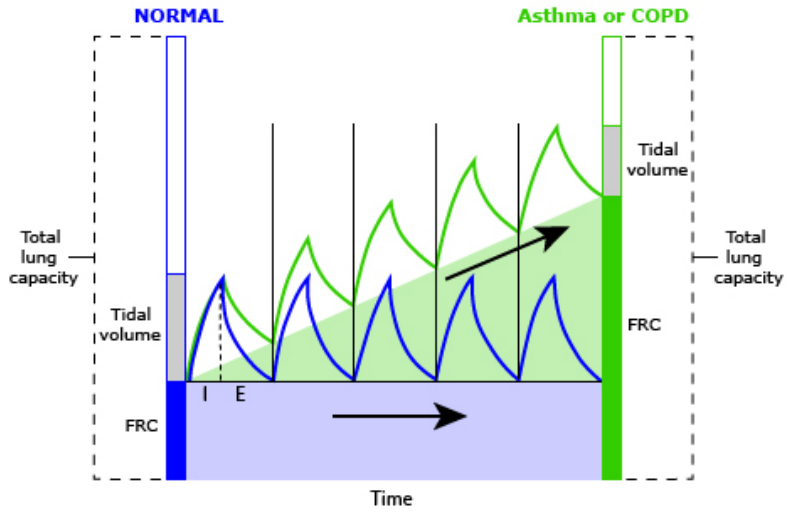
Height			PBW	Tidal volume				
Feet/inches	Inches	Centimeters	kg	4 mL/kg	5 mL/kg	6 mL/kg	7 mL/kg	8 mL/kg
4' 0"	48	122	17.9	72	90	107	125	143
4' 1"	49	124	20.2	81	101	121	141	162
4' 2"	50	127	22.5	90	113	135	158	180
4' 3"	51	130	24.8	99	124	149	174	198
4' 4"	52	132	27.1	108	136	163	190	217
4' 5"	53	135	29.4	118	147	176	206	235
4' 6"	54	137	31.7	127	159	190	222	254
4' 7"	55	140	34	136	170	204	238	272
4' 8"	56	142	36.3	145	182	218	254	290
4' 9"	57	145	38.6	154	193	232	270	309
4' 10"	58	147	40.9	164	205	245	286	327
4' 11"	59	150	43.2	173	216	259	302	346
5' 0"	60	152	45.5	182	228	273	319	364
5' 1"	61	155	47.8	191	239	287	335	382
5' 2"	62	157	50.1	200	251	301	351	401
5' 3"	63	160	52.4	210	262	314	367	419
5' 4"	64	163	54.7	219	274	328	383	438
5' 5"	65	165	57	228	285	342	399	456
5' 6"	66	168	59.3	237	297	356	415	474
5' 7"	67	170	61.6	246	308	370	431	493
5' 8"	68	173	63.9	256	320	383	447	511
5' 9"	69	175	66.2	265	331	397	463	530
5' 10"	70	178	68.5	274	343	411	480	548
5' 11"	71	180	70.8	283	354	425	496	566
6' 0"	72	183	73.1	292	366	439	512	585
6' 1"	73	185	75.4	302	377	452	528	603
6' 2"	74	188	77.7	311	389	466	544	622
6' 3"	75	190	80	320	400	480	560	640
6' 4"	76	193	82.3	329	412	494	576	658
6' 5"	77	196	84.6	338	423	508	592	677
6' 6"	78	198	86.9	348	435	521	608	695
6' 7"	79	201	89.2	357	446	535	624	714
6' 8"	80	203	91.5	366	458	549	641	732
6' 9"	81	206	93.8	375	469	563	657	750
6' 10"	82	208	96.1	384	481	577	673	769
6' 11"	83	211	98.4	394	492	590	689	787
7' 0"	84	213	100.7	403	504	604	705	806

PBW: predicted body weight.

Reproduced from: NHLBI ARDS Network. Available at: http://www.ardsnet.org/ (Accessed on November 20, 2012).

Graphic 87147 Version 5.0

Dynamic hyperinflation during controlled ventilation in obstructive lung disease



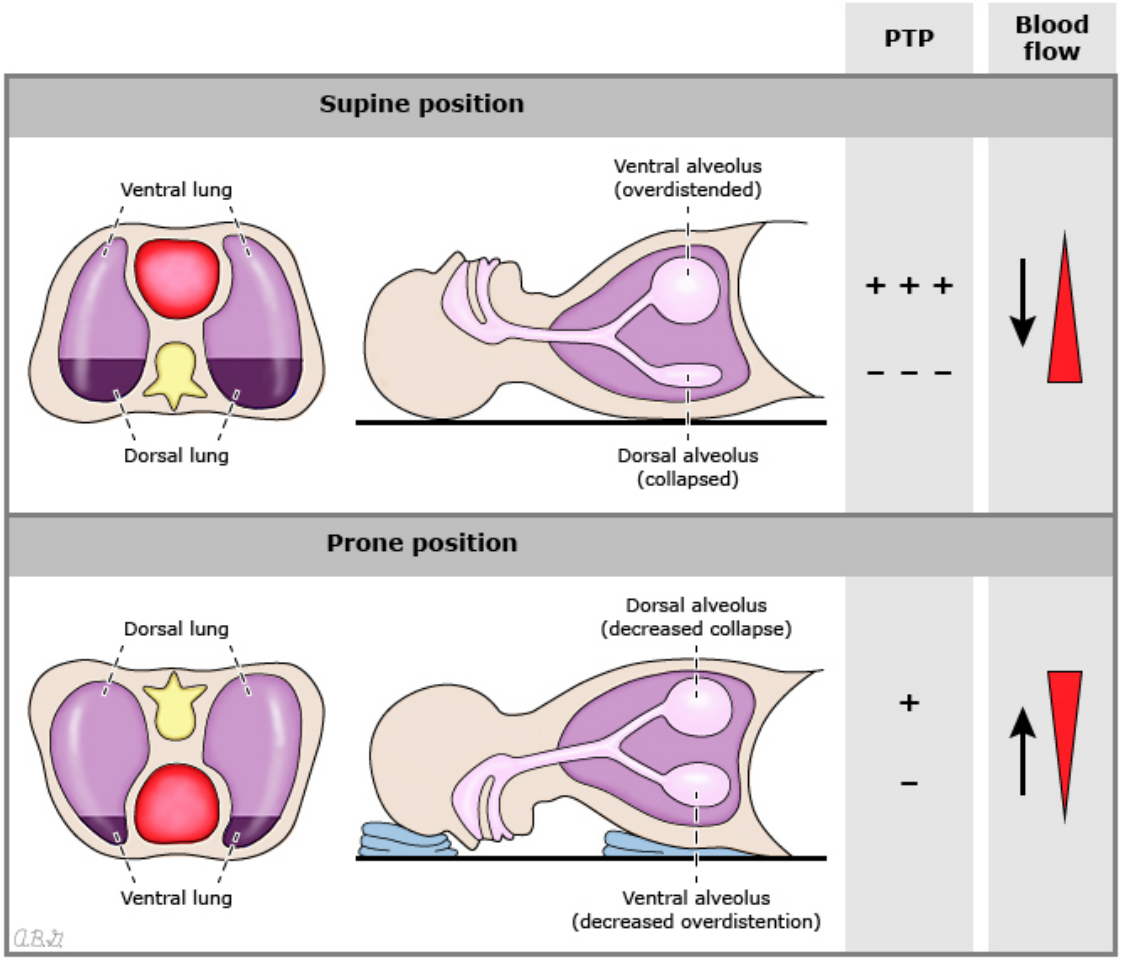
During resting ventilation of normal lungs or controlled ventilation of lungs with decreased lung compliance (eg, ARDS), passive exhalation leads to a return to normal FRC at the end of each breath. However, in patients with airway obstruction, such as asthma or COPD, exhalation may not be complete at the time the next breath is initiated, leading to increasing amounts of trapped air at end-exhalation, a process known as dynamic hyperinflation. In this figure, the tidal volume curve in blue reflects ventilation of normal lungs and shows a return to the normal FRC at the end of each exhalation. The tidal volume curve in green shows the progressive increase in FRC in a patient with asthma or COPD when successive breaths are initiated before complete exhalation. Dynamic hyperinflation can occur in patients with airway obstruction during mechanical ventilation or with exercise.
Dynamic hyperinflation is associated with increased intrathoracic pressure and potentially decreased venous return to the heart. Dynamic hyperventilation is treated by decreasing minute ventilation (ie, reducing tidal volume and/or respiratory rate) and sometimes by shortening inspiratory time to enable adequate time for exhalation.

ARDS: acute respiratory distress syndrome; COPD: chronic obstructive pulmonary disease; FRC: functional residual capacity; I: inspiration; E: expiration.

Adapted from: Tuxen DV. Permissive hypercapnic ventilation. Am J Respir Crit Care Med 1994; 150:870.

Graphic 78052 Version 6.0

Physiology of prone positioning in acute respiratory distress syndrome



Shown in this figure are axial (left) and sagittal views (right) of the thoracic cage representing the changes that occur as a consequence of prone positioning compared with supine positioning. Distending pressure of lung is determined by the transpulmonary pressure (PTP). When an individual is supine, the ventral PTP (+++) significantly exceeds the dorsal PTP (–––) resulting in greater expansion of the ventral alveoli than the dorsal alveoli; this effect is exaggerated in acute respiratory distress syndrome (ARDS) such that ventral alveoli become overdistended and dorsal alveoli become atelectatic (dark purple). Prone positioning reduces the difference between the dorsal and ventral PTP, making ventilation more homogeneous, leading to a decrease in dorsal alveolar overinflation and ventral alveolar collapse and recruitment of alveoli that had collapsed during the supine ventilation. In ARDS, there is substantial ventilation-perfusion mismatch in the supine position, since blood flow and alveolar collapse are both greatest in the dependent portions of the lung. When prone, ventilation/perfusion matching improves since the previously dependent lung continues to receive the majority of the blood flow as alveoli reopen, while the newly dependent lung continues to receive the minority of the blood flow as alveoli begin to collapse. NOTE: The terms dorsal and ventral are anatomy based, rather than gravity based.

Graphic 108807 Version 2.0

Vasopressors and inotropic agents used in the operating room: Adult dosing*¶

Drug	Functional class (predominant receptor or mechanism of action)	Bolus dose	Infusion dose	Comments
Ephedrine	Inotrope/chronotrope/vasopressor (alpha$_1$-adrenergic receptor agonist; beta$_1$- and beta$_2$-adrenergic receptor agonist)	5 to 10 mg boluses	N/A	▪ Tachyphylaxis may occur with multiple repeated doses due to indirect postsynaptic release of norepinephrine ▪ Cardiovascular effects attenuated by drugs that block ephedrine uptake into adrenergic nerves (eg, cocaine) or those that deplete norepinephrine reserves (eg, reserpine) ▪ Administered with extreme caution (eg, in small incremental doses of 2.5 mg) to patients using monoamine oxidase (MAO) inhibitors or methamphetamines since exaggerated hypertensive responses or life-threatening dysrhythmias may occur
Phenylephrine	Vasopressor (alpha$_1$-adrenergic receptor agonist)	50 to 100 mcg boluses (may begin infusion if repeated bolus doses are necessary)	10 to 100 mcg/minute or 0.1 to 1 mcg/kg/minute	▪ Often selected to treat hypotension if normal or elevated HR is present ▪ Genetic polymorphisms lead to variable individual responses
Norepinephrine	Inotrope/vasopressor (alpha$_1$- and beta$_1$-adrenergic receptor agonist)	4 to 8 mcg (may begin infusion if repeated bolus doses are necessary)	1 to 20 mcg/minute or 0.01 to 0.3 mcg/kg/minute	▪ Often selected as a first-line agent during noncardiac surgery, particularly for treatment of most types of shock ▪ Norepinephrine 8 mcg is approximately equivalent in potency to phenylephrine 100 mcg ▪ Peripheral extravasation of a high concentration may cause tissue damage
Epinephrine	Inotrope/chronotrope/vasopressor (alpha$_1$-adrenergic receptor agonist; beta$_1$- and beta$_2$-adrenergic receptor agonist)	4 to 10 mcg initially; up to 100 mcg boluses may be used when initial response is inadequate	1 to 100 mcg/minute or 0.01 to 1 mcg/kg/minute **Note changing effects across dose range:** ▪ Low doses have primarily beta$_2$-adrenergic effects at 1 to 2 mcg/minute or 0.01 to 0.02 mcg/kg/minute	▪ First-line treatment for cardiac arrest and for anaphylaxis ▪ May be administered IV, IM, or via an endotracheal tube in emergencies ▪ Low doses cause bronchodilatory effects and may cause arterial vasodilation and decreased BP

			▪ Intermediate doses have primarily beta$_1$- and beta$_2$-adrenergic effects at 2 to 10 mcg/minute or 0.02 to 0.1 mcg/kg/minute ▪ High doses have primarily alpha$_1$-adrenergic effects at 10 to 100 mcg/minute or 0.1 to 1 mcg/kg/minute	▪ Intermediate doses cause increases in HR and BP ▪ High doses cause vasoconstriction, with possible severe hypertension and adverse metabolic effects ▪ Individual responses to dose-related effect are variable
Vasopressin	Vasopressor (vasopressin$_1$ and vasopressin$_2$ receptor agonist)	1 to 4 units	0.01 to 0.04 units/minute Doses >0.04 units/minute up to 0.1 units/minute are reserved for salvage therapy (ie, failure to achieve adequate BP goals with other vasopressor agents) ¶	▪ Effective for treatment of hypotension refractory to administration of catecholamines or sympathomimetics such as ephedrine, phenylephrine, or norepinephrine ▪ No direct effect on HR ▪ Little effect on PVR; can cause splanchnic vasoconstriction ▪ Individual responses to dose-related effects are variable ▪ Peripheral extravasation may cause skin necrosis
Dopamine	Inotrope/vasopressor/dose-dependent chronotropy (dopaminergic, beta$_1$-, beta$_2$-, and alpha$_1$-adrenergic receptor agonist)	N/A	2 to 20 mcg/kg/minute **Note changing effects across dose range:** ▪ Low doses have primarily dopaminergic effects at <3 mcg/kg/minute ▪ Intermediate doses have primarily beta$_1$- and beta$_2$-adrenergic effects at 3 to 10 mcg/kg/minute ▪ High doses have primarily alpha$_1$-adrenergic effects >10 mcg/kg/minute	▪ Low doses may exacerbate hypotension via beta$_2$ stimulation ▪ High doses may cause vasoconstriction, adverse metabolic effects, and arrhythmias
Dobutamine	Inotrope/vasodilator/dose-dependent chronotropy (beta$_1$- and beta$_2$-adrenergic receptor agonist)	N/A	1 to 20 mcg/kg/minute	▪ Exacerbation of hypotension is possible due to dose-dependent vasodilation (via beta$_2$ stimulation); concurrent administration of a potent vasoconstrictor such as norepinephrine or vasopressin may be necessary
Milrinone	Inotrope/vasodilator (phosphodiesterase inhibitor) (decreases rate of cyclic adenosine monophosphate [cAMP] degradation)	N/A	0.375 to 0.75 mcg/kg/minute (a loading dose of 50 mcg/kg over ≥10 minutes may be administered, but is often omitted)	▪ Exacerbation of hypotension is likely due to vasodilation (via phosphodiesterase inhibition); concurrent administration of a potent vasoconstrictor such as norepinephrine or

				vasopressin may be necessary
Isoproterenol	Inotrope/chronotrope/vasodilator (beta$_1$- and beta$_2$-adrenergic receptor agonist)	N/A	5 to 20 mcg/minute or 0.05 to 0.2 mcg/kg/minute	▪ Exacerbation of hypotension is likely due to dose-dependent vasodilation (via beta$_2$ stimulation) ▪ May cause arrhythmias ▪ Not available in most settings

N/A: not applicable; HR: heart rate; IV: intravenous; IM: intramuscular; BP: blood pressure; PVR: pulmonary vascular resistance.
* Dose ranges are based on adult patients of normal size.
¶ Refer to related UpToDate content on hemodynamic management during anesthesia and surgery.

Graphic 119747 Version 1.0

Contributor Disclosures

Martin J London, MD, FASE Other financial interest: Springer Verlag [Anesthesia (journal honoraria)]; Lippincott Williams & Wilkins [Anesthesiology (journal handling editor)]. **Roberta Hines, MD** Nothing to disclose **Michael F O'Connor, MD, FCCM** Consultant/Advisory Boards: Intensix/CLEW [Predictive analytics in medicine]. **Nancy A Nussmeier, MD, FAHA** Nothing to disclose

Contributor disclosures are reviewed for conflicts of interest by the editorial group. When found, these are addressed by vetting through a multi-level review process, and through requirements for references to be provided to support the content. Appropriately referenced content is required of all authors and must conform to UpToDate standards of evidence.

Conflict of interest policy