Seminars in Cardiothoracic and Vascular Anesthesia
1–11

DOI: 10.1177/1089253220921590
journals.sagepub.com/home/scv
SAGE

Anesthesia and COVID-19: What We Should Know and What We Should Do

Linda Y. Tang[1] and Jingping Wang, MD, PhD[2]

Abstract

Coronavirus disease 2019 (COVID-19), caused by Severe Acute Respiratory Syndrome-Coronavirus-2 (SARS-CoV-2), was first reported in Wuhan, Hubei, China, and has spread to more than 200 other countries around the world. COVID-19 is a highly contagious disease with continuous human-to-human transmission. The origin of the virus is unknown. Airway manipulations and intubations, which are common during anesthesia procedures may increasingly expose anesthesia providers and intensive care unit team members to SARS-CoV-2. Through a comprehensive review of existing studies on COVID-19, this article presents the epidemiological and clinical characteristics of COVID-19, reviews current medical management, and suggests ways to improve the safety of anesthetic procedures. Owing to the highly contagious nature of the virus and the lack of therapeutic drugs or vaccines, precautions should be taken to prevent medical staff from COVID-19.

Keywords

COVID-19, coronavirus, SARS-CoV-2, MERS, PPE, RT-PCR test, anesthesia, epidemiology, pandemic, pneumonia

Introduction

Coronavirus disease 2019 (COVID-19) started as a cluster of pneumonia in Wuhan, Hubei, China, and was investigated by the Chinese Centers for Disease Control and Prevention (China CDC) at the end of 2019. A newly identified coronavirus, SARS-CoV-2, was the causative pathogen of COVID-19. Many of the initial patients had visited Wuhan Huanan Seafood Market. By the end of January 2020, China CDC described the epidemic characteristics of SARS-CoV-2 and confirmed human-to-human transmission; close contact with asymptomatic SARS-CoV-2 carriers could also transmit the disease.[1] Because of the "Spring Festival Rush" in China, this novel coronavirus rapidly spread into other provinces of China and subsequently into other countries around the world.[2-4] The World Health Organization (WHO) announced a Public Health Emergency of International Concern following the COVID-19 outbreak.[5] On March 11, the WHO officially recognized COVID-19 as a global pandemic, and the total number of cases and deaths outside China has overtaken the total number of cases in China.[6] On March 29, 2020, according to several live-updated sources, including Worldometer (https://www.worldometers.info/coronavirus/, Accessed March 29, 2020) and HealthMap of the Coronavirus Outbreak (healthmap.org/covid-19/, Accessed March 29, 2020), there were a total of 686 032 COVID-19 cases in more than 200 countries around the world and more than 32 200 deaths reported, posing a significant global health threat.[6,7] Besides China, countries significantly affected by COVID-19 include the United States, Italy, Iran, Spain, Germany, South Korea, and France (Figure 1).[6,7] People who had close contact with COVID-19 patients or traveled to the affected areas are at high risk of infection.

Our knowledge of COVID-19 is inadequate and limited. According to the Chinese authorities, medical staff are vulnerable to infection. Anesthesiologists, trainees, and nurse anesthetists are exposed to infectious droplets and aerosols when performing airway management on COVID-19 patients, and this is the primary route of infection.[9] Anesthesiologists, intensivists, trainees, Certified Anesthesia Assistants, and Certified Nurse Anesthetists should be up-to-date about the perioperative and intensive care unit (ICU) approach and management of these patients to ensure the safety of both patients and health care providers. In this review, we outline the

[1]Duke University Trinity College, Durham, NC, USA
[2]Harvard Medical School, Boston, MA, USA

Corresponding Author:
Jingping Wang, Department of Anesthesia, Critical Care and Pain Medicine, Massachusetts General Hospital, Harvard Medical School, 55 Fruit Street, GRJ 4-420, Boston, MA 02114, USA.
Email: Jwang23@MGH.Harvard.edu

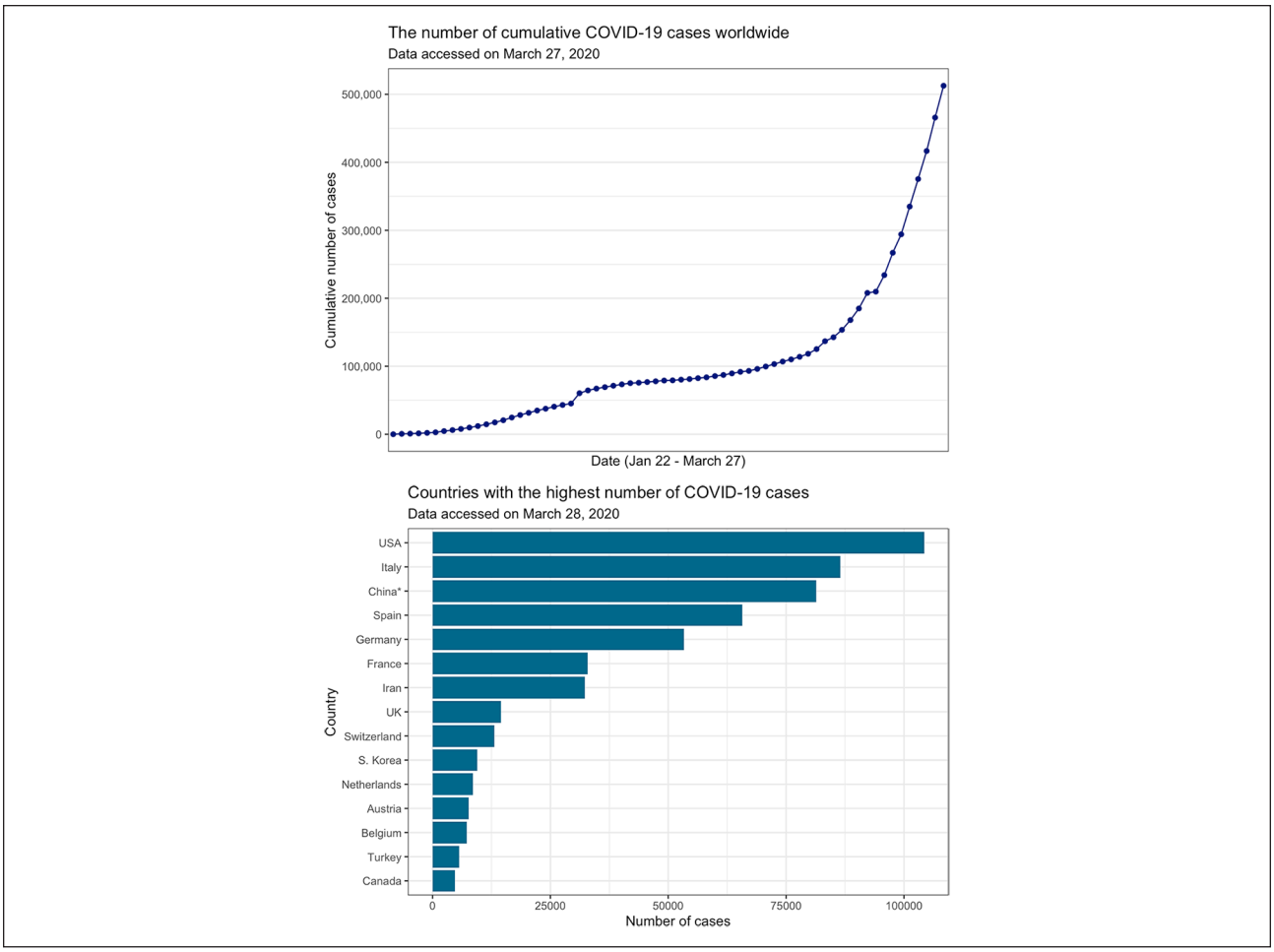

Figure 1. Cumulative number of COVID-19 cases worldwide and countries with the highest number of COVID-19 cases.[7,8]

epidemiology of SARS-CoV-2 and clinical features of COVID-19 to facilitate understanding of the disease and outline management strategies for anesthesia providers when taking care of patients with confirmed COVID-19 or persons undergoing investigation and how the risk of SARS-CoV-2 transmission could be minimized.

Methods

Publication searching was conducted using PubMed with "coronavirus," "COVID-19," "SARS-CoV-2," and "anesthesia" and we reviewed the "Coronavirus Center" of the *New England Journal of Medicine*, Elsevier, Wiley, Springer Nature. We also followed Chinese CDC, US CDC, and WHO. We collected articles linked to the novel coronavirus available in preprint websites. Both studies in English and Chinese were reviewed. This was a narrative review given the novelty and the timely need to disclose the findings of the study to the readership of the *Seminars in Cardiothoracic and Vascular Anesthesia*.

Origin and Transmission of SARS-CoV-2

SARS-CoV-2 is a positive-sense RNA virus belonging to the coronavirus family. Its diameter varies from about 60 to 140 nm, and its surface is covered with spike glycoprotein, a trimeric structure resembling a crown (Figure 2).[10,11] SARS-CoV-2 was first discovered at Wuhan Huanan Seafood Market where wild animals were sold.[1,12] The first cluster of CDC-investigated patients in China mostly visited the market, and the virus was assumed to have spread through animal-to-human transmission.[1] Zhou et al[13] suggested that bats were probably the natural reservoir host of SARS-CoV-2 because it shares more than 85% identity with a bat SARS-like CoV.[14-16] Researchers assumed that intermediate hosts, including pangolins and snakes, played a critical role in SARS-CoV-2 transmission and the subsequent COVID-19 outbreak.[17,18] Haplotype analysis of the whole genomic data suggested that the Huanan haplotype was derived from somewhere else, leading to the

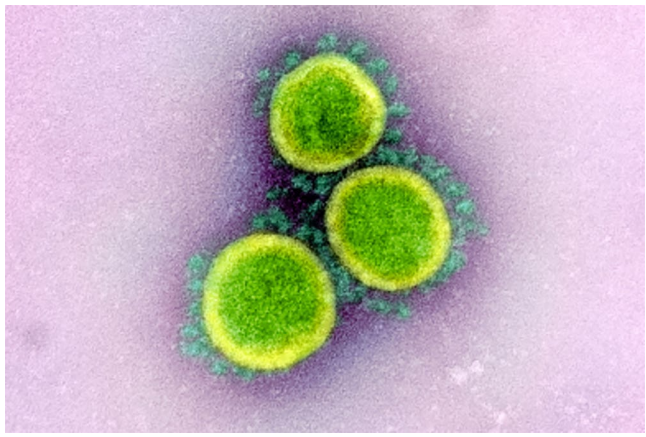

Figure 2. The structure of Severe Acute Respiratory Syndrome-Coronavirus-2 (SARS-CoV-2).[10]

possibility that the SARS-CoV-2 source was imported. The crowded market acted as the communication hub, which boosted SARS-CoV-2 circulation and spread it to the whole city by the end of 2019. Although Wuhan was the early epicenter of the COVID-19 outbreak, the virus subsequently spread around the world, with hot spots developing in Italy, Spain, and the United States.[19]

When more COVID-19 cases were investigated, human-to-human transmission was confirmed and attributed to the majority of the current COVID-19 cases.[1,2,12,14,20-25] Chinese scientists revealed that only 1.18% of the patients had direct contact with wild animals, and 71.80% of the patients had contact with other Wuhan residents.[20] Basic reproduction number (R_0) of an infection can be thought of as the expected number of cases directly generated by 1 case in a population, where all individuals are susceptible to infection; the current R_0 for COVID-19 is estimated to be between 1.4 to 3.9.[26]

Close contact with COVID-19 patients or absorbing droplets via the respiratory tract are established transmission pathways of SARS-CoV-2.[2] Chan et al[23] described that secretions of the respiratory tract contain the virus, with the highest viral load detected in the lower respiratory tract. Transmission through the ocular surface is still in debate. Lu et al[27] asserted that SARS-CoV-2 can easily contaminate the human conjunctival epithelium. Researchers identified SARS-CoV-2 in tears and conjunctival secretions of a few COVID-19 patients, suggesting the possibility for ophthalmic transmission.[28] However, Zhou et al[29] claimed that it is unlikely that SARS-CoV-2 transmits aerosol contact with the conjunctiva. Of the 67 COVID-19 cases included and studied, who were mostly health care workers and female nurses, only 1 patient had conjunctivitis but without negative conjunctival sac SARS-CoV-2 test. Three patients tested positive or probable positive for SARS-CoV-2.[29] However, the absence of repeated tests at different time points may contribute to some of the observed false-negative results. Xia et al[28] found SARS-CoV-2 in 2 interval collection of tears and conjunctival secretions in 1 common type patient out of 30 COVID-19 confirmed cases. As a result, it is plausible that SARS-CoV-2 could cause infection through close eye contact, but the chances for that is likely very low. Thus, eye protection is needed for ophthalmologists and health care providers such as anesthesia providers whose procedures potentially involve aerosol generation.

The fecal-oral transmission route is also possible. In the report of the first COVID-19 case in the United States, both stool and respiratory specimens tested positive by real-time reverse transcriptase polymerase chain reaction (rRT-PCR) for SARS-CoV-2.[30] Moreover, Yong et al[31] and other research groups isolated SARS-CoV-2 from the stool samples of COVID-19 patients especially those with digestive symptoms, confirming live virus in the stool.[30-34]

Structural analysis revealed that SARS-CoV-2 possibly transmits to humans via binding to the angiotensin-converting enzyme 2 (ACE2) receptor, and its binding affinity is higher than that of SARS-CoV.[35] Consequently, cells expressing higher ACE2 are the primary targets for SARS-CoV-2. Using single-cell transcriptomes, Zhang et al[32] showed that the upper esophageal mucosal cells, stratified epithelial cells, and absorptive enterocytes from the ileum and colon have been identified as cells with high ACE2 expression, making the digestive system a potential route for SARS-CoV-2 infection. Recently, 8 children persistently tested positive on rectal swabs even after nasopharyngeal testing was negative, supporting the fecal-oral transmission.[36] However, gastrointestinal symptoms such as diarrhea are uncommon in COVID-19 patients.[12,20,22,37]

Previously, a 30-hour-old infant was also diagnosed with SARS-CoV-2, which was likely transmitted via the

intrauterine vertical route.[38] However, a retrospective study of 9 COVID-19 infected pregnant women did not support such a maternal-infant vertical transmission.[39] More research is needed to reach a definite answer on maternal-infant vertical transmission.

In addition to symptomatic patients being a source of infection, asymptomatic patients may act as carriers of the virus because people in close contact with asymptomatic patients have acquired COVID-19, and virus isolated from asymptomatic patients was similar to that in the symptomatic patients.[23,24,40,41] Bai et al[42] reported an asymptomatic carrier who infected 5 other people with SARS-CoV-2 during a 19-day incubation period. Mizumoto et al[43] estimated that 15.5% to 20.2% of the total cases are asymptomatic carriers from observations of cases on the *Diamond Princess* cruise ship. Having asymptomatic carriers may result in underestimating the size of the infected population because asymptomatic carriers or patients with mild symptoms are typically excluded from being actual COVID-19 positive patients. Qiu[44] suggested that at least 59% of the infected individuals had mild or no symptoms, and they were not being tested and were potentially infecting others. As such, asymptomatic carriers could pose a significant potential risk for the anesthesia team when such a patient is present for surgery; of note, members of the surgical and anesthesia team could be asymptomatic carriers too, exposing their team members and patients to the virus.

Furthermore, China CDC reported that close contact with people in the incubation period of COVID-19 can result in infection.[45] Moreover, some patients who recovered from COVID-19 and had been discharged had positive RT-PCR test results, although they remained asymptomatic and no close contacts were infected during the follow-up period[46]; this finding suggests that even patients who recovered have the potential to be infectious.

In conclusion, studies suggested that SARS-CoV-2 is highly contagious, and consistent human-to-human transmission is observed. Respiratory inhalation of airborne droplets was the main transmission method.[1,2,12,20-23] Ocular surface and fecal-oral routes are possibly secondary transmission routes.[23,28,30-32] In addition, we need to be cautious of asymptomatic patients and patients during their incubation period.

Clinical Features of COVID-19

COVID-19 is a highly contagious disease, and its clinical symptoms include fever, cough, and shortness of breath.[20-22] The incubation period of COVID-19 ranges from 1 to 14 days; it is typically between 3 and 7 days, although few patients experienced longer incubation periods.[1,20,21] The median age of COVID-19 patients in Wuhan, Hubei, China, was around 50 to 60 years old, and more male individuals tested positive than female individuals.[1,12,20-22,47]

SARS-CoV-2 has 77% sequence identity with the Severe Acute Respiratory Syndrome (SARS) coronavirus,[48] but it is more contagious and initially induces milder symptoms. The death toll of COVID-19 has surpassed the total mortality of SARS and Middle East Respiratory Syndrome. Of those patients with COVID-19, 5% to 26% have required admission to the ICU for respiratory care.[20,21] The overall fatality is 1.36% to 4.3%, but it can vary by country.[20,21] The mortality rate was estimated to be 4% in China,[2,20] although it was initially higher in Wuhan.[12,21] Currently, Italy has the highest morality rate (9.5%), followed by Iran and Spain.[49] According to the US CDC, 994 deaths were reported out of 68 440 cases, suggesting a 1.4% mortality rate.[50]

The severity of the disease can vary between age groups. Older adults with serious underlying medical conditions such as diabetes mellitus or ischemic heart disease are at the highest risk for more serious complications.[2,20,47] It has been estimated that between 31% and 70% of the patients older than 85 years of age required hospitalization, much higher than that for younger adults.[51] Older patients were most frequently admitted to the ICU,[21,23,47] more likely to develop acute respiratory distress syndrome, and more likely to require mechanical ventilation.[2,12,47] People with asthma, HIV, or other immunodeficiencies are also at elevated risk for respiratory complications.[51] However, some more recent data has indicated that 20% of patients between the ages of 20 to 40 years required hospital admission and/or intensive medical therapy.[51] In addition, medical personnel are at a higher risk for a more severe form of the disease.

A confirmed COVID-19 case is defined as one where SARS-CoV-2 is detected in respiratory secretions, which is the most reliable method for SARS-CoV-2 testing.[21,23,33,34,40,41,47,52] As for symptoms of COVID-19, fever (83%-98%) was the most common, followed by cough (46%-82%), shortness of breath (31%), myalgia or fatigue (38.1%), nausea or vomiting, and diarrhea.[12,15,20-23,37,53] Respiratory symptoms include rhinorrhea, sneezing, sore throat, and pneumonia.[54] It is worth noting that less than 50% of COVID-19 patients had fever on admission but 88.7% of them subsequently developed fever during hospitalization.[20] In the study by Chen et al[55] in China, the clinical progression of COVID-19 showed a biphasic pattern. The first phase was characterized by fever, cough, fatigue, and other systemic symptoms; the disease progressed as evidenced by radiological worsening within 7 days after onset of symptoms.[55] High viral loads in the upper-respiratory tract samples suggests a high risk of transmissibility during the first several days of symptoms.[56] However, symptoms began to relieve in most of the

patients as the disease progressed into week 2, in which half of the patients restored normal body temperature and became PCR negative, although most patients later developed bilateral pneumonia and respiratory insufficiency.[55] With regard to diagnostic workup, chest computed tomography (CT) imaging typically reveals ground-glass opacity as the most common radiological finding.[20,57] As the patient's symptoms of pneumonia progressed within the next 1 to 3 weeks, bilateral ground-glass opacities tended to decrease, whereas consolidation and mixed patterns became more common.[57] However, chest CT abnormalities were observed even in asymptomatic patients, or sometimes symptomatic patients were found without chest CT abnormalities.[12,20,37,57] According to laboratory findings, lymphocytopenia was present in most patients, followed by thrombocytopenia and leukopenia.[20,52] The combination of hypoalbuminemia, lymphopenia, high concentrations of C-reactive protein, and lactate dehydrogenase may predict the severity and progression of the disease.[52]

Current Medical Management of COVID-19

Because of its novelty, no specific medication is known to treat COVID-19. Researchers are striving to repurpose current antiviral medications, such as HIV drugs lopinavir/ritonavir, and/or developing new ones. In addition, researchers across the globe have been working on developing a vaccine. Of the known antiviral medications, remdesivir, which is a broad-spectrum antiviral with properties of inhibiting RNA-dependent polymerase, shows high promise.[58] Wang et al[59] found that remdesivir potently blocks SARS-CoV-2 infection at low micromolar concentrations in vitro.[58] Similarly, Holshue et al[30] reported encouraging results of remdesivir in the treatment of a patient with COVID-19 in the United States.[58] Favipiravir, a drug developed for treating novel influenza in China, has also been studied. It is a new type of RNA-dependent RNA polymerase inhibitor.[60] Of the known nonantiviral medications, chloroquine phosphate, a widely used antimalarial medication, has been shown to have apparent anti-SARS-CoV-2 properties with efficacy for treating COVID-19. It blocks viral entry into endosome, and it has successfully inhibited exacerbation of pneumonia and improved lung imaging findings.[59,61] Other potentially effective drugs include cepharanthine, selamectin, and mefloquine hydrochloride.[62] In the absence of effective vaccines or medications, nonpharmacological measures such as social distancing and quarantine have become the most important response strategies for slowing down the spread of the virus. Quarantine is compulsory for symptomatic COVID-19 patients. In the United States, in the early phase of the spread of the virus, self-quarantine for 14 days was/is necessary after traveling to a CDC Level 3 Travel Health Notice country or after being in close contact with a COVID-19 patient.[63] According to the US CDC, it is recommended to avoid close contact with sick people, practice social distancing, clean and disinfect frequently touched surfaces daily, and cover coughs and sneezes; these policies are constantly being updated as the spread of the disease progresses.[6] Special attention and efforts to protect or reduce transmission should be given to susceptible populations like health care providers and elderly people.[6] On March 16, President Trump advised the public to avoid gathering in groups of more than 10 people at a White House news conference.[64] This strategy is known as "flatten the curve" to avoid dramatic increase in new cases, which will surpass the US health care capacity and overwhelm US hospital systems as has already happened in other countries.[65,66] As of March 29, 27 states in the United States have enacted Stay at Home laws, limiting travel and congregation of residents, in an effort to mandate social distancing.

Recommendations for Anesthesia Procedures

COVID-19 has brought serious threats to the safety of health care workers in addition to the general public. At the epicenters, the overburdened health care system and shortage of personal protective equipment (PPE) have magnified the risk of frontline medical staff to exposure. In China, a total of 3.5% of health care workers were infected with COVID-19, and their mortality rate was about 0.3%.[2,20] Among health care workers, anesthesiologists are at even higher risk for infection because of their close contact with infected patients and the high potential exposure to respiratory droplets or aerosol from infected patients during airway manipulations.[11] Current data suggest that approximately 3.2% of patients with COVID-19 required intubation and invasive ventilation at some point during the course of the disease.[67] Anesthesia team members could encounter COVID-19 positive patients in emergency settings, ICU to operating room (OR) transfer for ECMO (extracorporeal membrane oxygenation), or getting reassigned to help with offsite emergency airway management. We will discuss below what anesthesia personnel should do to minimize their risk for infection; the recommendations described below are a universal approach to reducing transmission and may vary from institution to institution according to the availability of the team members, PPE, and local guidelines and could also change as we gain more experience.

1. *Preoperative preparations*: Upon the arrival of a COVID-19 patient, anesthesia personnel should prepare the designated ORs only for patients with COVID-19 with "infectious surgery" labeled on

Components	Recommendations
Oxygen	Make sure an adequate supply of oxygen is available and prepare a separate oxygen tank in the room
Machine	Make sure an anesthesia machine or an ICU ventilator is functional
Suction	Make sure suction (with backup) is functional and available
Monitor	Make sure pulse oximetry, electrocardiography and noninvasive blood pressure monitors are functional
Drugs	Have all drugs for sedation, anesthesia induction and muscle relaxation available
Intravenous access	Flush and make sure intravenous access is functional
Airway Supplies	Make sure the video laryngoscope (with backup) is functional and prepare a difficult airway cart

Figure 3. Flowcharts on how to properly don (top) and doff (bottom) before and after surgical operations.[78]

the door.[11] It is recommended to turn off positive pressure and turn on negative pressure if available. The in-room anesthesia care team should inform the OR charge nurse and other providers that the patient with COVID-19 is to be transferred to the designated OR.[11] COVID-19 positive or suspect patients in need of preoperative anesthesia assessment should be visited by the primary anesthesia attending.[11] Adding to the routine preoperative evaluations, anesthesiologists should assess the patient's respiratory status and cardiovascular function. Before having any physical contact with the patient, anesthesiologists should wear PPE, including a fit-tested N95 or higher-level respirator, such as a comprehensive respiratory protective device with a powered air purifier and a positive-pressure medical protective hood if available, disposable work caps, goggles and full-face shield, and fluid-resistant gown, gloves, and shoe cover.[9,68-71] The proper sequence of putting on PPE is as follows: putting on scrubs and hair cover → hand disinfection → putting on the mask → putting on inner gloves → putting on the coverall → putting on eye protection (goggles/face shield) → putting on foot protection → putting on the isolation gown → putting on outer gloves → test the fit of the PPE components (Figure 3).[11] Although most PPEs are designed to be single use only, in periods of critical shortage, gowns may be worn to see multiple patients with the same infectious disease diagnosis and may be worn for multiple surgeries where the surgical procedure has a low risk of contamination.[72] Surgical masks or N95 respirators may be worn for extended periods during care for multiple patients. Postponing elective procedures that require the use of PPE and increasing the use of washable PPE are recommended.[72]

2. *Anesthesia*: General anesthesia is recommended to reduce airborne and droplet transmission through the patient's mouth and nose. (Spinal anesthesia is still recommended as the primary choice of anesthesia for cesarean delivery in a mother with COVID-19, and the infected mother must wear a surgical mask or N95 mask all the time).[11] Rapid sequence induction is recommended because bag mask ventilation could increase the risk for aerosolizing airway secretions, with a higher likelihood for viral exposure and transmission.[67] If possible, a "Negative Pressure Airway Hood" is recommended (https://www.youtube.com/watch?v=FYEqKPOAT44, Accessed March 27, 2020) to prevent staff from the droplets and aerosol exposure. After satisfactory preoxygenation, apply the induction and paralysis agent in short succession to each other; 1 to 2 mg intravenous midazolam may be considered for sedation for extremely anxious patients. Intravenous lidocaine, 1.5 mg/kg, is effective in suppressing airway reflexes during endotracheal intubation. Tracheal intubation is a high-risk procedure that can cause the patient to spray secretions or blood, or produce droplets or aerosols,

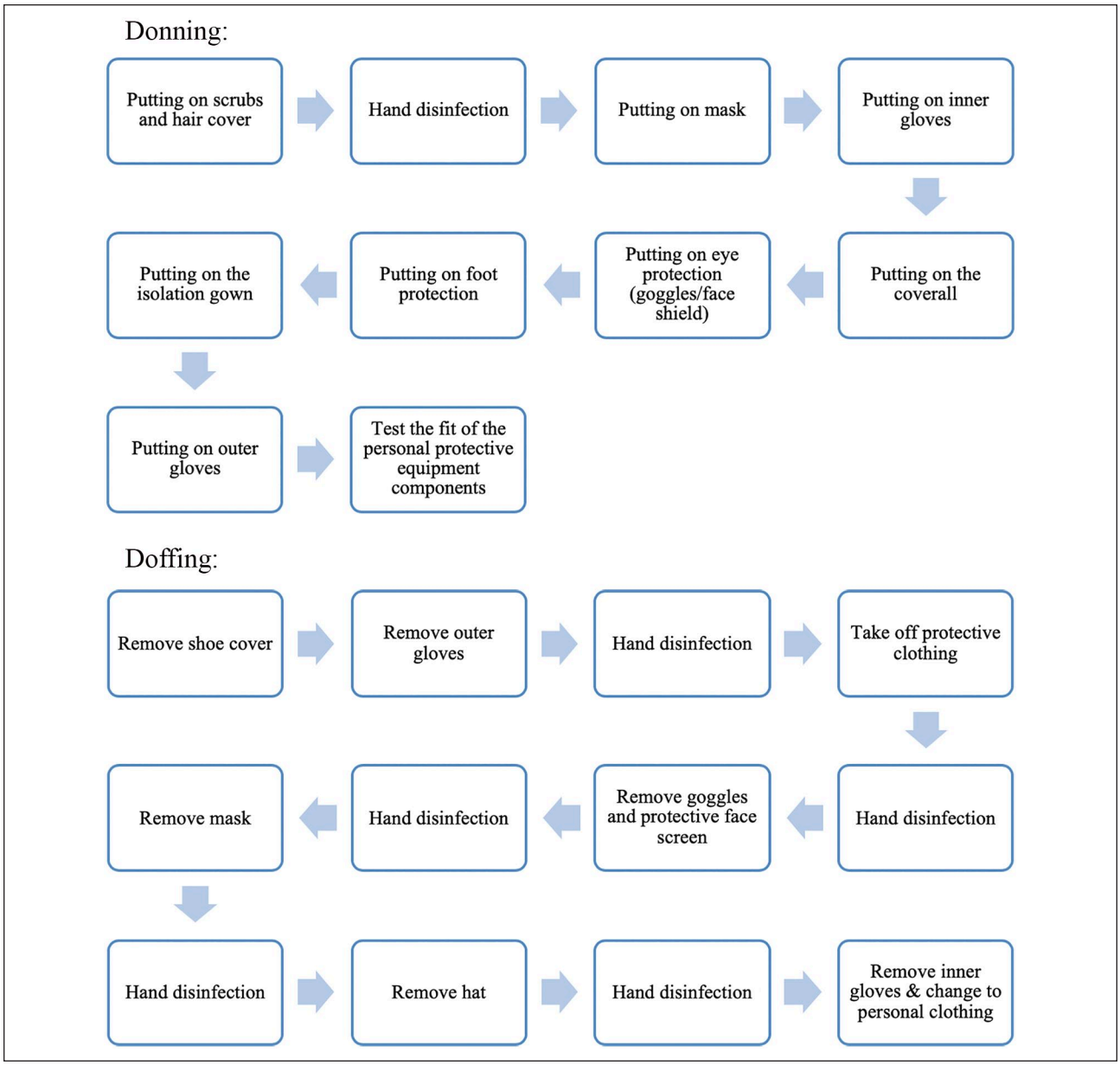

Figure 4. Recommendations for intubation preparation for patients with confirmed or suspected COVID-19.[67,79]

increasing the exposure of medical staff to COVID-19.[9,68] Because of the shortage of PPE, some medical centers have designated the most experienced anesthesia professional as the primary intubator for a specific room and day, who will wear N95, goggles, and other relevant PPE.[73] Before the procedure, anesthesiologists should confirm tight connections on standard breathing circuit and use video laryngoscopy to maximize distance between the intubator and the airway (Figure 4).[2,9,68,74] During the procedure, it is recommended to use a long-acting muscle relaxant to minimize coughing, inflate cuff prior to ventilation, confirm correct tube position with end tidal CO_2, and place a ventilator on standby immediately prior to extubation.[67,68,74] Medical personnel involved in the care of the patients should first change gloves after airway manipulation and then use other OR items, such as anesthesia computer or anesthesia cart, to reduce the spread of SARS-CoV-2.[71] The anesthesia cart can be covered by a clear plastic sheet once the presumed supplies for the case are gathered, to limit cross-contamination.

3. *Anesthesia recovery*: After the operation, it is recommended to send the COVID-19 patient to an isolated room in the ICU, bypassing the postanesthesia care unit. However, such policies are subject to change when the health care system gets overwhelmed, as in major epicenters such as New York. Extubation can be performed in the original OR when the patient's condition is stable.[68] Before extubation, 2 layers of wet gauze can be used to cover the patient's nose and mouth to minimize exposure to the patient's secretions.[11] In the ICU, if the patient's respiratory distress and/or hypoxemia cannot be eased after receiving standard oxygen therapy and their condition does not improve after 2 hours of high-flow nasal catheter oxygen therapy or noninvasive ventilation (manifested as respiratory distress, breathing frequency >30 times/min, and oxygenation index <150 mm Hg), tracheal intubation should be performed in time.[11]
4. *Transporting patients*: Nurses and anesthesiologists should wear PPE outside of the OR, and the patient should be covered with disposable surgical linen and transported in a special elevator. One person should clear the transfer channel in advance to reduce the exposure of unrelated personnel. The patient must wear a surgical mask or N95 mask during transfer; providers should wear medical protective masks during transport whether the patient is intubated or not.[69]
5. *Postanesthesia equipment care and disposal of PPE*: Contaminated anesthesia equipment such as the video laryngoscope blade or the reinforced tubes should be single use and disposed properly. Before being taken out of the contaminated area, all medical waste should be double-bagged and labeled "COVID-19," along with the name of the department, institute, date, time, and the category; all the packing bags should be sealed and sprayed with chlorinated disinfectant or covered with an additional bag and sealed.[11] All nondisposable anesthesia equipment should be cleaned and disinfected with 2% to 3% hydrogen peroxide, 2 to 5 g/L chlorine disinfectant wipes, or 75% alcohol wipes.[11] All medical personnel involved in the actual surgical case should take off and dispose their PPE into designated biohazard disposal bags or containers according to the local infection control policy. Protective clothing and other nondisposable items should be wrapped in medical waste packaging bags and placed in designated areas for special handling. The sequence of properly removing PPE is as follows: remove shoe cover → remove outer gloves → hand disinfection → take off protective clothing → hand disinfection → remove goggles and protective face screen → hand disinfection → remove mask → hand disinfection → remove hat → hand disinfection → remove inner gloves → change to personal clothing (Figure 3).[68,71] According to the American Society of Anesthesiologists, extreme caution is needed when removing and disposing PPE to minimize the risk of self-contamination; adding an observer to observe the provider while disposing PPE could further minimize self-contamination. Hand hygiene should be performed using alcohol-based hand rubs with 60% to 95% alcohol or hand washing with soap and water for at least 20 s.[75]
6. *Management of medical staff when exposure occurs*: After an exposure, health care workers should assess their COVID-19 exposure risk according to the US CDC guidelines and report to their supervisor or occupational health services immediately.[76] Health care workers at high risk for infection should stop all health care interactions with patients for 14 days after the last day of exposure to a confirmed COVID-19 patient, be tested for COVID-19, and quarantined for 14 days.[20-22,46,52] During the observation period, body temperature and respiratory symptoms are monitored daily. However, if critical shortage of medical staff occurs and ways of improving staffing have been exhausted, it is permitted for an asymptomatic health care worker who has been exposed to work, after consultation with occupational health services.[77] They should always wear a facemask when being in the health care facility, avoid contact with severely immunocompromised patients, and adhere to hand hygiene and respiratory hygiene.[77] Health care workers at low risk for COVID-19 should self-monitor temperature and respiratory symptoms daily for 14 days after the last day of exposure to a COVID-19 patient, notify health care facility immediately if they develop any symptoms suggestive of COVID-19, and reinforce contact and droplet precautions.[77] Follow-ups are needed in other medical procedures with no confirmed COVID-19 patients as well because it is uncertain whether patients who recovered from COVID-19 have the potential to transmit SARS-CoV-2.[46]

Conclusion

In this review, we summarized the origin and potential transmission routes of SARS-CoV-2 and also assessed the clinical features and current medical management of COVID-19. We provided recommendations for anesthesia procedures to minimize anesthesia personnel and other health care workers' risk of infection. As the number of

confirmed COVID-19 cases worldwide rises rapidly and health care systems are getting overwhelmed, as manifested by the shortage of PPE and medical staff, coordinated effort is needed to slow down the spread of the virus; it is particularly important for anesthesia personnel and other health care workers to be cautious and adhere to guidelines to protect the safety of their patients and colleagues. Future research and clinical studies are needed to develop effective treatments for COVID-19.

In the meantime, developing and updating guidelines and recommendations for the management of COVID-19 positive patients and patients under investigation (PUI) may help reduce the risk for viral exposure and transmission in anesthesia personnel and other health care workers, which can save precious personnel resources in the time of a pandemic.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iDs

Linda Y. Tang https://orcid.org/0000-0003-2865-5378
Jingping Wang https://orcid.org/0000-0003-2699-1650

References

1. Li Q, Guan X, Wu P, et al. Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. *N Engl J Med*. 2020;382:1199-1207.
2. The Novel Coronavirus Pneumonia Emergency Response Epidemiology Team. The epidemiological characteristics of an outbreak of 2019 novel coronavirus diseases (COVID-19)—China, 2020 [in Chinese]. *China CDC Weekly*. 2020;2:113-122.
3. Rothe C, Schunk M, Sothmann P, et al. Transmission of 2019-nCoV infection from an asymptomatic contact in Germany. *N Engl J Med*. 2020;382:970-971.
4. Wei M, Yuan J, Liu Y, Fu T, Yu X, Zhang ZJ. Novel coronavirus infection in hospitalized infants under 1 year of age in China [published online February 14, 2020]. *JAMA*. doi:10.1001/jama.2020.2131
5. World Health Organization. Statement on the second meeting of the International Health Regulations (2005) Emergency Committee regarding the outbreak of novel coronavirus (2019-nCoV). Published January 30, 2020. Accessed April 8, 2020.
6. Centers for Disease Control and Prevention. How to protect yourself & others. https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/prevention.html?CDC_AA_refVal=https%3A%2F%2Fwww.cdc.gov%2Fcoronavirus%2F2019-ncov%2Fprepare%2Fprevention.html. Accessed April 8, 2020.
7. Worldometer. Coronavirus update (live). https://www.worldometers.info/coronavirus/?utm_campaign=homeAdvegas1?. Accessed April 8, 2020.
8. World Health Organization Emergency Dashboard. Coronavirus (COVID-19). https://who.sprinklr.com/. Accessed April 8, 2020.
9. Tran K, Cimon K, Severn M, Pessoa-Silva CL, Conly J. Aerosol generating procedures and risk of transmission of acute respiratory infections to healthcare workers: a systematic review. *PLoS One*. 2012;7:e35797.
10. National Institute of Allergy and Infectious Disease. Novel coronavirus SARS-CoV-2 [photo]. https://www.flickr.com/photos/niaid/49640655213/. Accessed April 8, 2020.
11. Chen X, Liu Y, Gong Y, et al. Perioperative management of patients infected with the novel coronavirus: recommendation from the Joint Task Force of the Chinese Society of Anesthesiology and the Chinese Association of Anesthesiologists [published online March 26, 2020]. *Anesthesiology*. doi:10.1097/ALN.0000000000003301
12. Chen N, Zhou M, Dong X, et al. Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study. *Lancet*. 2020;395:507-513.
13. Zhou P, Yang XL, Wang XG, et al. A pneumonia outbreak associated with a new coronavirus of probable bat origin. *Nature*. 2020;579:270-273. doi:10.1038/s41586-020-2012-7
14. Lu R, Zhao X, Li J, et al. Genomic characterisation and epidemiology of 2019 novel coronavirus: implications for virus origins and receptor binding. *Lancet*. 2020;395:565-574.
15. Zhu N, Zhang D, Wang W, et al. A novel coronavirus from patients with pneumonia in China, 2019. *N Engl J Med*. 2020;382:727-733.
16. Wu F, Zhao S, Yu B, et al. A new coronavirus associated with human respiratory disease in China. *Nature*. 2020;579:265-269.
17. Xiao K, Zhai J, Feng Y, et al. Isolation and characterization of 2019-nCoV-like coronavirus from Malayan pangolins [published online February 20, 2020]. *bioRxiv*. doi:10.1101/2020.02.17.951335
18. Ji W, Wang W, Zhao X, Zai J, Li X. Cross-species transmission of the newly identified coronavirus 2019-nCoV. *J Med Virol*. 2020;92:433-440.
19. Yu WB, Tang GD, Zhang L, Corlett RT. Decoding evolution and transmissions of novel pneumonia coronavirus (SARS-CoV-2) using the whole genomic data. https://www.researchgate.net/publication/339351990_Decoding_evolution_and_transmissions_of_novel_pneumonia_coronavirus_SARS-CoV-2_using_the_whole_genomic_data. Accessed April 8, 2020.
20. Guan WJ, Ni ZY, Hu Y, et al. Clinical characteristics of coronavirus disease 2019 in China [published online February 28, 2020]. *N Engl J Med*. doi:10.1056/NEJMoa2002032
21. Wang D, Hu B, Hu C, et al. Clinical characteristics of 138 hospitalized patients with 2019 novel coronavirus–infected pneumonia in Wuhan, China [published online February 7, 2020]. *JAMA*. doi:10.1001/jama.2020.1585
22. Huang C, Wang Y, Li X, et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet*. 2020;395:497-506.

23. Chan JFW, Yuan S, Kok KH, et al. A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: a study of a family cluster. *Lancet*. 2020;395:514-523.
24. Pan X, Chen D, Xia Y, et al. Asymptomatic cases in a family cluster with SARS-CoV-2 infection. *Lancet Infect Dis*. 2020;20:410-411.
25. Sun K, Chen J, Viboud C. Early epidemiological analysis of the coronavirus disease 2019 outbreak based on crowdsourced data: a population-level observational study. *Lancet Digit Health*. 2020;2:PE201-PE208. doi:10.1016/S2589-7500(20)30026-1
26. Wu JT, Leung K, Bushman M, et al. Estimating clinical severity of COVID-19 from the transmission dynamics in Wuhan, China [published online March 19, 2020]. *Nat Med*. doi:10.1038/s41591-020-0822-7
27. Lu CW, Liu XF, Jia ZF. 2019-nCoV transmission through the ocular surface must not be ignored. *Lancet*. 2020;395:e39.
28. Xia J, Tong J, Liu M, Shen Y, Guo D. Evaluation of coronavirus in tears and conjunctival secretions of patients with SARS-CoV-2 infection [published online February 26, 2020]. *J Med Virol*. doi:10.1002/jmv.25725
29. Zhou Y, Zeng Y, Tong Y, Chen CZ. Ophthalmologic evidence against the interpersonal transmission of 2019 novel coronavirus through conjunctiva [published online February 12, 2020]. *medRxiv*. doi:10.1101/2020.02.11.20021956
30. Holshue ML, DeBolt C, Lindquist S, et al; Washington State 2019-nCoV Case Investigation Team. First case of 2019 novel coronavirus in the United States. *N Engl J Med*. 2020;382:929-936. doi:10.1056/NEJMoa2001191
31. Yong Z, Cao C, Shuangli Z, et al. Isolation of 2019-nCoV from a stool specimen of a laboratory-confirmed case of the coronavirus disease 2019 (COVID-19) [in Chinese]. *China CDC Weekly*. 2020;2:123-124.
32. Zhang H, Kang Z, Gong H, et al. The digestive system is a potential route of 2019-nCov infection: a bioinformatics analysis based on single-cell transcriptomes [published online January 31, 2020]. *bioRxiv*. doi:10.1101/2020.01.30.927806
33. Pan Y, Zhang D, Yang P, Poon LLM, Wang Q. Viral load of SARS-CoV-2 in clinical samples. *Lancet Infect Dis*. 2020;20:411-412. doi:10.1016/S1473-3099(20)30113-4
34. Young BE, Ong SWX, Kalimuddin S, et al; Singapore 2019 Novel Coronavirus Outbreak Research Team. Epidemiologic features and clinical course of patients infected with SARS-CoV-2 in Singapore [published online March 3, 2020]. *JAMA*. doi:10.1001/jama.2020.3204
35. Wrapp D, Wang N, Corbett KS, et al. Cryo-EM structure of the 2019-nCoV spike in the prefusion conformation. *Science*. 2020;367:1260-1263. doi:10.1126/science.abb2507
36. Xu Y, Li X, Zhu B, et al. Characteristics of pediatric SARS-CoV-2 infection and potential evidence for persistent fecal viral shedding [published online March 13, 2020]. *Nat Med*. doi:10.1038/s41591-020-0817-4
37. Xu XW, Wu XX, Jiang XG, et al. Clinical findings in a group of patients infected with the 2019 novel coronavirus (SARS-Cov-2) outside of Wuhan, China: retrospective case series. *BMJ*. 2020;368:m606.
38. XinhuaNet. Newborn infected with coronavirus in China's Wuhan. http://www.xinhuanet.com/english/2020-02/05/c_138758788.htm. Published February 5, 2020. Accessed April 8, 2020.
39. Chen H, Guo J, Wang C, et al. Clinical characteristics and intrauterine vertical transmission potential of COVID-19 infection in nine pregnant women: a retrospective review of medical records. *Lancet*. 2020;395:809-815. doi:10.1016/S0140-6736(20)30360-3
40. Hoehl S, Rabenau H, Berger A, et al. Evidence of SARS-CoV-2 infection in returning travelers from Wuhan, China. *N Engl J Med*. 2020;382:1278-1280.
41. Zou L, Ruan F, Huang M, et al. SARS-CoV-2 viral load in upper respiratory specimens of infected patients. *N Engl J Med*. 2020;382:1177-1179.
42. Bai Y, Yao L, Wei T, et al. Presumed asymptomatic carrier transmission of COVID-19 [published online February 21, 2020]. *JAMA*. doi:10.1001/jama.2020.2565
43. Mizumoto K, Kagaya K, Zarebski A, Chowell G. Estimating the asymptomatic proportion of coronavirus disease 2019 (COVID-19) cases on board the *Diamond Princess* cruise ship, Yokohama, Japan, 2020. *Euro Surveill*. 2020;25. doi:10.2807/1560-7917.ES.2020.25.10.2000180
44. Qiu J. Covert coronavirus infections could be seeding new outbreaks [published online March 20, 2020]. *Nature*. doi:10.1038/d41586-020-00822-x
45. Ping W, Zhiyong L, Ye C, Ying Q, Huijie C, Xiangdong A. Investigation of a cluster of 2019 novel coronavirus disease (COVID-19) with possible transmission during the incubation period—Shenyang City, China 2020 [in Chinese]. *China CDC Weekly*. 2020;2:125-127.
46. Lan L, Xu D, Ye G, et al. Positive RT-PCR test results in patients recovered from COVID-19 [published online February 27, 2020]. *JAMA*. doi:10.1001/jama.2020.2783
47. Yang X, Yu Y, Xu J, et al. Clinical course and outcomes of critically ill patients with SARS-CoV-2 pneumonia in Wuhan, China: a single-centered, retrospective, observational study [published online February 24, 2020]. *Lancet Respir Med*. doi:10.1016/S2213-2600(20)30079-5
48. Zhou Y, Hou Y, Shen J, Huang Y, Martin W, Cheng F. Network-based drug repurposing for novel coronavirus 2019-nCoV/SARS-CoV 2. *Cell Discov*. 2020;6:14.
49. Johns Hopkins University & Medicine. Johns Hopkins Coronavirus Resource Center. https://coronavirus.jhu.edu/. Accessed March 25, 2020.
50. Centers for Disease Control and Prevention. Cases in US. https://www.cdc.gov/coronavirus/2019-ncov/cases-updates/cases-in-us.html. Accessed April 8, 2020.
51. Centers for Disease Control and Prevention. People who are at higher risk for severe illness. https://www.cdc.gov/coronavirus/2019-ncov/need-extra-precautions/people-at-higher-risk.html. Accessed April 8, 2020.
52. Liu Y, Yang Y, Zhang C, et al. Clinical and biochemical indexes from 2019-nCoV infected patients linked to viral loads and lung injury. *Sci China Life Sci*. 2020;63:364-374. doi:10.1007/s11427-020-1643-8
53. Auwaerter PG. Coronavirus COVID-19 (SARS-CoV-2). https://www.hopkinsguides.com/hopkins/.//view/Johns_Hopkins_ABX_Guide/540747/all/Coronavirus_COVID_19__SARS_CoV_2_?refer=true. Accessed March 28, 2020.

54. Rothan HA, Byrareddy SN. The epidemiology and pathogenesis of coronavirus disease (COVID-19) outbreak [published online February 26, 2020]. *J Autoimmun*. doi:10.1016/j.jaut.2020.102433
55. Chen J, Qi T, Liu L, et al. Clinical progression of patients with COVID-19 in Shanghai, China [published online March 19, 2020]. *J Infect*. doi:10.1016/j.jinf.2020.03.004
56. Lescure FX, Bouadma L, Nguyen D, et al. Clinical and virological data of the first cases of COVID-19 in Europe: a case series [published online March 27, 2020]. *Lancet Infect Dis*. doi:10.1016/S1473-3099(20)30200-0
57. Shi H, Han X, Jiang N, et al. Radiological findings from 81 patients with COVID-19 pneumonia in Wuhan, China: a descriptive study. *Lancet Infect Dis*. 2020;20:425-434. doi:10.1016/S1473-3099(20)30086-4
58. Dong L, Hu S, Gao J. Discovering drugs to treat coronavirus disease 2019 (COVID-19). *Drug Discov Ther*. 2020;14:58-60.
59. Wang M, Cao R, Zhang L, et al. Remdesivir and chloroquine effectively inhibit the recently emerged novel coronavirus (2019-nCoV) in vitro. *Cell Res*. 2020;30:269-271.
60. Shiraki K, Daikoku T. Favipiravir, an anti-influenza drug against life threatening RNA virus infections [published online February 22, 2020]. *Pharmacol Ther*. doi:10.1016/j.pharmthera.2020
61. Gao J, Tian Z, Yang X. Breakthrough: chloroquine phosphate has shown apparent efficacy in treatment of COVID-19 associated pneumonia in clinical studies. *Biosci Trends*. 2020;14:72-73.
62. Fan HH, Wang LQ, Liu WL, et al. Repurposing of clinically approved drugs for treatment of coronavirus disease 2019 in a 2019-novel coronavirus (2019-nCoV) related coronavirus model [published online March 6, 2020]. *Chin Med J (Engl)*. doi:10.1097/CM9.0000000000000797
63. Centers for Disease Control and Prevention. Coronavirus disease 2019 (COVID-19). https://www.cdc.gov/coronavirus/2019-ncov/index.html. Accessed April 8, 2020.
64. Brady JS. Remarks by President Trump, Vice President Pence, and Members of the Coronavirus Task Force in Press Briefing. https://www.whitehouse.gov/briefings-statements/remarks-president-trump-vice-president-pence-members-coronavirus-task-force-press-briefing-19/. Published April 4, 2020. Accessed April 8, 2020.
65. Godoy M. Flattening a pandemic's curve: why staying home now can save lives. https://www.npr.org/sections/health-shots/2020/03/13/815502262/flattening-a-pandemics-curve-why-staying-home-now-can-save-lives. Published March 13, 2020. Accessed April 8, 2020.
66. Roberts S. Flattening the coronavirus curve. *The New York Times*. https://www.nytimes.com/article/flatten-curve-coronavirus.html. Published March 27, 2020. Accessed April 8, 2020.
67. Meng L, Qiu H, Wan L, et al. Intubation and ventilation amid the COVID-19 outbreak: Wuhan's experience [published online March 26, 2020.]. *Anesthesiology*. doi:10.1097/ALN.0000000000003296
68. Wax RS, Christian MD. Practical recommendations for critical care and anesthesiology teams caring for novel coronavirus (2019-nCoV) patients [published online February 12, 2020]. *Can J Anaesth*. doi:10.1007/s12630-020-01591-x
69. Radonovich LJ Jr, Simberkoff MS, Bessesen MT, et al. N95 respirators vs medical masks for preventing influenza among health care personnel: a randomized clinical trial. *JAMA*. 2019;322:824-833. doi:10.1001/jama.2019.11645
70. Cabrini L, Landoni G, Zangrillo A. Minimise nosocomial spread of 2019-nCoV when treating acute respiratory failure. *Lancet*. 2020;395:685. doi:10.1016/S0140-6736(20)30359-7
71. Centers for Disease Control and Prevention. Interim infection prevention and control recommendations for patients with confirmed coronavirus disease 2019 (COVID-19) or persons under investigation for COVID-19 in healthcare settings 2020. https://www.cdc.gov/coronavirus/2019-ncov/hcp/infection-control-recommendations.html?CDC_AA_refVal=https%3A%2F%2Fwww.cdc.gov%2Fcoronavirus%2F2019-ncov%2Finfection-control%2Fcontrol-recommendations.html. Accessed April 17, 2020.
72. American Veterinary Medical Association. Guidelines for use of personal protective equipment (PPE) during the COVID-19 pandemic when demand exceeds supply. https://www.avma.org/resources-tools/animal-health-and-welfare/covid19/guidelines-ppe-covid-19-pandemic-demand-exceeds. Accessed April 8, 2020.
73. Anesthesia Patient Safety Foundation. Perioperative considerations for the 2019 novel coronavirus (COVID-19). https://www.apsf.org/news-updates/perioperative-considerations-for-the-2019-novel-coronavirus-covid-19/. Published February 12, 2020. Accessed April 8, 2020.
74. Massachusetts General Hospital. Best practices for management of suspected or confirmed COVID-19.
75. Centers for Disease Control and Prevention. Interim infection prevention and control recommendations for patients with suspected or confirmed coronavirus disease 2019 (COVID-19) in healthcare settings. https://www.cdc.gov/coronavirus/2019-ncov/infection-control/control-recommendations.html. Accessed April 8, 2020.
76. World Health Organization. Health workers exposure risk assessment and management in the context of COVID-19 virus: interim guidance. https://apps.who.int/iris/bitstream/handle/10665/331340/WHO-2019-nCov-HCW_risk_assessment-2020.1-eng.pdf?sequence=1&isAllowed=y. Published March 4, 2020. Accessed April 8, 2020.
77. Centers for Disease Control and Prevention. Interim US guidance for risk assessment and public health management of healthcare personnel with potential exposure in a healthcare setting to patients with coronavirus disease (COVID-19). https://www.cdc.gov/coronavirus/2019-ncov/hcp/guidance-risk-assesment-hcp.html. Accessed April 8, 2020.
78. AlibabaCloud. Global MediXchange for combating COVID-19. https://www.alibabacloud.com/covid-19-global-medix-change. Accessed March 25, 2020.
79. Harvard Medical School Teaching Hospital. Perioperative/procedural workflow.