Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Current Practices

Personal Protective Equipment: Current Best Practices for Orthopedic Teams

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ABSTRACT

The coronavirus disease (COVID-19) pandemic caused by the severe acute respiratory syndrome (SARS-CoV-2) virus is challenging healthcare providers across the world. Current best practices for personal protective equipment (PPE) during this time are rapidly evolving and fluid due to the novel and acute nature of the pandemic and the dearth of high-level evidence. Routine infection control practices augmented by airborne precautions are paramount when treating the COVID-19-positive patient. Best practices for PPE use in patients who have unknown COVID-19 status are a highly charged and emotional issue. The variables to be considered include protection of patients and healthcare providers, accuracy and availability of testing, and responsible use of PPE resources. This article also explores the concerns of surgeons regarding possible transmission to their own family members as a result of caring for COVID-19 patients.

Humanity is faced with managing the pandemic of the coronavirus disease (COVID-19) caused by the severe acute respiratory syndrome (SARS-CoV-2) virus. Orthopedic surgeons are being confronted with the challenges of treating patients who have an extremely contagious disease. In 1735, Benjamin Franklin concisely said, "An ounce of prevention is worth a pound of cure." It is paramount that orthopedic surgeons understand the rapidly evolving recommendations to achieve viral infection control. This article reviews infection control precautions, use of personal protective equipment (PPE), methods to help optimize PPE supplies during the pandemic, and approaches to limit transmission to the family members of healthcare workers. One must understand that the existing evidence is not high level and the recommendations are fluid secondary to the novel and acute nature of this viral pandemic.

Types of Infection Control Precautions

The United States Healthcare Infection Control Practices Advisory Committee (HICPAC) and Centers for Disease Control and Prevention (CDC) provide the guidelines that hospitals implement across the country to prevent infectious transmission between patients and healthcare workers [1]. The HICPAC/CDC guidelines are centered on the mode of transmission of each disease. The transmission-based precautions include contact, droplet, and airborne precautions [2]. In theory, SARS-CoV-2 could be transmitted via a blood-borne pathway but additional precautions are not necessary secondary to universal precautions against blood-borne pathogens that have been standard of care in the healthcare setting. The CDC has provided guidance on standard precautions that should be utilized for all patient care and in diseases where additional transmission-based precautions are necessary [2,3].

Standard Precautions

Standard precautions are common sense measures intended to be used when the healthcare worker could be exposed to bodily

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fluids, nonintact skin, and/or mucous membranes [3]. Historically, standard precautions included hand hygiene, correct use of PPE, proper handling of injections and sharp objects, appropriate cleaning of equipment, and disposal of used equipment [3–5]. After the severe acute respiratory syndrome (SARS) epidemic, infectious disease experts observed that the lack of source (ie, infected subject) control added to disease transmission [1]. As a result, the concept of "respiratory hygiene/cough etiquette" was added to the standard precautions [1]. Respiratory hygiene/cough etiquette is meant to apply to all individuals in a healthcare setting including patients and visitors.

Contact Precautions

The most common mode of transmission is contact, which has been divided into direct and indirect contact [1]. Direct contact transmission is the transfer of the disease through contact with the patient. Indirect contact transmission is the transfer of the disease through contact with a vector such as contaminated equipment or a person. Contact precautions limit both modes of disease transmission through placement of the patient in a single room, use of gloves and gown during contact with the patient or the patient's environment, limited transportation of the patient with adherence to precautions when necessary, use of disposable or dedicated patient equipment with appropriate disposal, and decontamination of the equipment and room [1,2,4,5]. In the event that the patient cannot be placed in a single-patient room, the patient beds must have at least 3 feet between the beds and systems implemented to prevent inadvertent sharing of equipment or other items [1].

Droplet Precautions

Droplet transmission occurs through direct or indirect contact with contaminated 30- to 50-μm respiratory droplets that enter through the nasal mucosa, conjunctiva, and/or mouth [4,6]. In the healthcare setting, respiratory droplets are most commonly produced via coughing, sneezing, talking, suctioning, endotracheal intubation, and cardiopulmonary resuscitation. Droplet precautions limit the transmission of respiratory droplets through placement of the patient in single room, use of a mask during direct patient contact, limited transportation of the patient, and adherence to precautions during necessary transport [1,2,4,5]. When the patient requires transportation within the healthcare facility or placement in a multipatient room, source control can be achieved through use of a mask on the patient and placement of the beds at least 3 feet apart [1]. Special airborne infection isolation rooms (AIIR) are not necessary because the pathogen does not remain infectious over long distances [1].

Airborne Precautions

Airborne transmission occurs when contaminated small ($\leq$5 μm in size) respirable particles are aerosolized and become suspended in the airflow [4,7]. For reference, coronaviruses are typically 0.125 μm in diameter [8]. The main difference in infectious disease spread between droplet and airborne transmission is that airborne diseases have the ability to disperse over long distances and remain infective for an extended period of time [1,4,7]. Currently, the CDC is uncertain about the ability of SARS-CoV-2 to be transmitted as small respirable particles and over long distances [4]. Although the mode of transmission for COVID-19 is believed to be through respiratory droplets, the recommended PPE for healthcare workers has been for airborne precautions when possible [9,10]. Airborne precautions are designed to reduce transmission of small respirable particles and prevent dispersion over long distances through placement of the patient in a single-patient AIIR, use of an N95 or higher-level respirator during direct patient contact, and limited transportation of the patient with adherence to precautions during necessary transport [1,2,4,5,7]. When transportation is required within the healthcare facility, or placement is needed in a single-patient room not equipped as an AIIR, source control can be achieved by the patient wearing a mask [1].

Recommended Precautions for Orthopedic Teams Specific to COVID-19

In response to COVID-19, different healthcare centers have implemented a variety of often evolving policies for healthcare personnel PPE. This is a highly charged and emotional issue for which there is a dearth of high-level evidence. The variables to be considered include protection of patients and healthcare providers, accuracy and availability of testing, and responsible use of PPE resources.

Operating on the Confirmed or Suspected COVID-19-Positive Patient

Surgery on COVID-19 patients should only be considered in the urgent or emergent setting and elective cases should be postponed. A study of 1099 patients with COVID-19 demonstrated that 19% present with shortness of breath, 41% require supplemental oxygen, 5% become critically ill, and 2.3% require invasive mechanical ventilation [11]. Additional precautions include, if possible, a designated operating room (OR) with negative pressure for COVID-19-positive patients throughout the duration of the pandemic [12,13]. Ideally, this OR should be separate from the main OR complex with minimal traffic flow. Rodrigues-Pinto et al [14] outline a 5-zone COVID-19 OR. Additional staffing and transportation workflows can also be implemented [15]. The untested, symptomatic, presumed COVID-19-positive patient requiring surgery, in the authors' opinion, should be treated as if confirmed positive.

Preoperatively, the patient should be masked and ideally all providers wear N95 respirators. The N95 mask, when consistently and properly worn, is effective against airborne particles. A recent study of orthopedic surgeons from Wuhan, China, reported that not wearing an N95 respirator mask was a significant risk factor for the development of COVID-19 (odds ratio, 5.20; 95% confidence interval, 1.09-25.00) [16]. When there is a shortage of N95 respirators, the CDC recommends prioritizing N95 respirators for aerosol-producing procedures [10]. It is the authors' recommendation that if source control is lost because the patient cannot wear a mask, providers should wear an N95 respirator.

Once the patient reaches the OR, however, the COVID-19 patient will need airway management with removal of any mask leading to contamination of the room for all personnel, not just anesthesia providers. The presence in the OR of only essential staff during endotracheal intubation is recommended as the risk of aerosolization and droplet transmission is increased [17]. All personnel, upon entering the room, should wear N95 masks, eye/face protection, gloves, and gowns. PPE should be donned and removed according to established protocols [9].

A special consideration for orthopedic surgeries is the use of power instruments and pulsatile lavage, which are aerosol generating [18]. Orthopedic procedure transmission of viral disease through aerosols has been an ongoing concern [19,20]. Transmission of SARS-CoV-2 by this route has not been reported, perhaps because the aerosols are not from the respiratory tree. Another unique consideration for arthroplasty surgeons is the utilization of surgical hoods (ie, "spacesuits"). Multiple sources, including formal memos from industry, have stated that this equipment alone is not protective against SARS-CoV-2 [19,21,22]. These hoods do not filter

enough particles in the 0.02- to 1-μm-diameter range to meet the standard for protective respirators [19]. This class of PPE is primarily utilized for protection against in-motion debris and was never designed as a respiratory protection system [22]. Based on current available evidence, surgical hoods can still be used for COVID-19-positive patients, but must be in conjunction with an N95 respirator [19]. Importantly, the ideal technique for proper cleaning of the helmets (including the hard-to-access fans utilized in the ventilation system) remains to be defined.

Operating on Patients Without Confirmed or Suspected COVID-19

There are a substantial proportion of asymptomatic infected patients [23]. It may be prudent to test all patients preoperatively, if possible. In a study by Lei et al [24], asymptomatic patients unknown to be in the incubation phase of the infection experienced mortality rates as high as 20% and rates of intensive care unit admission of 44% as their disease became apparent postoperatively. One important testing concern is the possibility of false-negative results both with the standard swabs and the more recent released rapid test systems [25,26]. Due to the prevalence of asymptomatic disease and the lack of accurate testing at this time, proactive PPE use for healthcare providers during the pandemic including the use of N95 respirators at all times may be warranted.

At the time of this writing, elective arthroplasty is not commonly being performed in the United States. When elective operations resume, it may be prudent to test all patients before surgery during the waning pandemic [15]. The aggressive testing of all preoperative patients, if testing accuracy, availability, and timing allow, is one strategy to reduce the risk for all parties as we resume elective arthroplasty.

PPE Outside of the Operating Room

PPE utilization for the orthopedic surgeon outside of the OR is based on the current CDC recommendations for all personnel in the healthcare setting [9]. When possible, N95 respirators should be utilized by all healthcare personnel working with or near COVID-19-positive patients. In situations where shortage of N95 respirators precludes the utilization by all personnel, surgical masks can be substituted, with the recognition of their reduced effectiveness for preventing airborne transmission. Bartoszko et al [27] demonstrated the effectiveness of surgical masks for preventing droplet transmission in most scenarios. In a meta-analysis of available literature, Offeddu et al [28] demonstrated equivalence between standard surgical masks and respirator masks for healthcare workers in preventing infection of viral respiratory illnesses. However, these studies were on influenza and do not consider the potential increased transmissibility of SARS-CoV-2 [28]. In addition to N95 respirators, additional protection typically worn for airborne precautions is required. This includes an isolation gown, face shield or goggles, and gloves [9]. There is some evidence that in the setting of COVID-19, the N95 respirator should be worn at all times in the hospital [16].

Methods for Extending N95 Respirator Supply

There are grave concerns regarding a sudden surge in COVID-19 cases leaving PPE in short supply, as has been seen in New York State. The CDC has provided guidance on strategies to optimize the rate of PPE consumption, allowing for use outside the manufacturer's instructions and expiration date [29–32]. Broadly, the PPE supply strategies are conservation, extension of use, and decontamination with reuse.

The primary method for conservation of PPE supply is the delay of elective and nonurgent surgical procedures [29–32]. Other techniques include altering the annual N95 fit testing (ie, just-in-time training, qualitative testing, or temporarily suspending testing), decreasing hospital length of stay for medically stable COVID-19 patients, limiting face-to-face encounters with COVID-19 patients, and excluding visitors to COVID-19 patients [29–32].

Extended use of an N95 is not recommended under normal circumstances, but the practice of wearing the same N95 respirator during repeated encounters with different patients can help extend the supply of N95 respirators [32]. The CDC does not recommend the extended use of the same N95 respirator for more than 8 to 12 hours [32].

The CDC has been working on the development of evidence-based protocols for decontamination of disposable filtering facepiece (DFFP) N95 respirators that maintain filtration and tight-fit capacity [33]. An additional resource has been N95DECON, a consortium of scientists, engineers, and clinicians who are working to provide up-to-date evidence-based statements on the decontamination of DFFP N95 respirators [34]. The use of vaporous hydrogen peroxide (VHP), ultraviolet germicidal irradiation (UVGI), and moist heat are promising methods for decontamination of DFFP N95 respirators [33,34]. As of yet, however, none of these promising methods have been evaluated for decontamination of SARS-CoV-2 on DFFP N95 respirators; as such, their ability to decontaminate similar viruses is used as a proxy [34]. The VHP cycle takes approximately 6 to 8 hours and whole-room decontamination systems have been described that allows for decontamination of 700 N95 respirators in a 12 × 12 foot room [34]. The respirators appear to maintain filtration and tight-fit for approximately 20 to 50 cycles [34]. The UVGI process provides a more rapid cycle of only approximately 30 seconds and maintains filtration and tight-fit for approximately 10 to 20 cycles but does not allow for as many DFFP N95 respirators in a single cycle and "shadowing" can lead to incomplete decontamination [34]. The use of moist heat takes approximately 30 minutes depending on the temperature and humidity but it most rapidly degrades the filtration and tight-fit with respirators only withstanding 1 to 5 cycles [34]. Although decontamination with VHP, UVGI, or moist heat demonstrates promising results, not all manufacturers and models of the respirators have been tested under these conditions. Therefore, the CDC and N95DECON provide recommendations for the type of decontamination and number of cycles for specific manufacturers and models of a DFFP N95 respirator [33,34].

Autoclave, dry heat, isopropyl alcohol, soap, dry microwave irradiation, bleach, or disinfection wipes are not recommended because they lead to more rapid degradation of the respirator's filtration capacity [33,34]. Ethylene oxide is not recommended because it is carcinogenic [33].

Protecting Your Family From COVID-19

Transmission of COVID-19 to those close to us is a concern all healthcare providers share. In their study of 26 orthopedic surgeons infected with SARS-CoV-2, Guo et al [16] demonstrated a substantial risk of transmission to others. They report confirmed transmission in 25% of cases, including family members (5 [20.8%]), colleagues (1 [4.2%]), patients (1 [4.2%]), and friends (1 [4.2%]). The authors report that this high rate of transmission led to "great stress and depression for these surgeons." Their recommendation, for orthopedic surgeons working in hospital settings during the pandemic, was to avoid close contact with family members at home [16]. This is obviously a difficult recommendation to follow from both a psychological and pragmatic standpoint. Currently, there is little clinical evidence to guide recommendations. The American

College of Surgeons recommends removing and washing clothes immediately upon arrival at home, cleaning cell phones before and after patient care activities, frequent hand washing, and reducing physical contact with family members [17]. In addition, they recommend that healthcare institutions and systems allow for hotel accommodations for healthcare workers who cannot, or prefer not to, go home following patient care activities.

Conclusion

The COVID-19 pandemic caused by the SARS-CoV-2 virus has had a devastating human and economic toll. Viral outbreaks may be of concern even after the current pandemic has faded. The challenge of caring for patients in the face of rapidly evolving and often conflicting data is reflected in the fluidity of currently published guidelines by the CDC and other governmental agencies. The orthopedic surgeon should strive to be up-to-date on the latest evidence to protect their patients, their colleagues, their families, and themselves.

References

[1] Siegel JD, Rhinehart E, Jackson M, Chiarello L, Health Care Infection Control Practices Advisory C. 2007 Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Health Care Settings. https://www.cdc.gov/infectioncontrol/pdf/guidelines/isolation-guidelines-H.pdf [accessed 10.04.20].

[2] Centers for Disease Control and Prevention. Transmission-based precautions. https://www.cdc.gov/infectioncontrol/basics/transmission-based-precautions.html [accessed 10.04.20].

[3] Centers for Disease Control and Prevention. Standard Precautions for All Patient Care. https://www.cdc.gov/infectioncontrol/basics/standard-precautions.html [accessed 10.04.20].

[4] Douedi S, Douedi H. In: Precautions, bloodborne, contact, and droplet. Treasure Island, FL: StatPearls; 2020.

[5] Broussard IM, Kahwaji CI. In: Universal precautions. Treasure Island, FL: StatPearls; 2020.

[6] Hall CB, Douglas Jr RG, Schnabel KC, Geiman JM. Infectivity of respiratory syncytial virus by various routes of inoculation. Infect Immun 1981;33:779–83.

[7] Ather B, Edemekong PF. In: Airborne precautions. Treasure Island, FL: StatPearls; 2020.

[8] Fehr AR, Perlman S. Coronaviruses: an overview of their replication and pathogenesis. Methods Mol Biol 2015;1282:1–23. https://doi.org/10.1007/978-1-4939-2438-7_1.

[9] Centers for Disease Control and Prevention. Using personal protective equipment (PPE). https://www.cdc.gov/coronavirus/2019-ncov/hcp/using-ppe.html [accessed 10.04.20].

[10] 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/hcp/infection-control-recommendations.html [accessed 14.04.20].

[11] Guan WJ, Ni ZY, Hu Y, Liang WH, Ou CQ, He JX, et al., China Medical Treatment Expert Group for C. Clinical characteristics of coronavirus disease 2019 in China. N Engl J Med 2020. https://doi.org/10.1056/NEJMoa2002032.

[12] Centers for Disease Control and Prevention. Coronavirus Disease 2019 (COVID-19) Situation Summary. https://www.cdc.gov/coronavirus/2019-ncov/cases-updates/summary.html [accessed 07.04.20].

[13] Ti LK, Ang LS, Foong TW, Ng BSW. What we do when a COVID-19 patient needs an operation: operating room preparation and guidance. Can J Anaesth 2020. https://doi.org/10.1007/s12630-020-01617-4.

[14] Rodrigues-Pinto R, Sousa R, Oliveira A. Preparing to perform trauma and orthopaedic surgery on patients with COVID-19. J Bone Joint Surg Am 2020. https://doi.org/10.2106/JBJS.20.00454.

[15] Wong J, Goh QY, Tan Z, Lie SA, Tay YC, Ng SY, et al. Preparing for a COVID-19 pandemic: a review of operating room outbreak response measures in a large tertiary hospital in Singapore. Can J Anaesth 2020. https://doi.org/10.1007/s12630-020-01620-9.

[16] Guo X, Wang J, Hu D, Wu L, Gu L, Wang Y, et al. Survey of COVID-19 disease among orthopaedic surgeons in Wuhan, people's Republic of China. J Bone Joint Surg Am 2020. https://doi.org/10.2106/JBJS.20.00417.

[17] American College of Surgeons. COVID 19: considerations for optimum surgeon protection. https://www.facs.org/covid-19/clinical-guidance/surgeon-protection [accessed 07.04.20].

[18] Judson SD, Munster VJ. Nosocomial transmission of emerging viruses via aerosol-generating medical procedures. Viruses 2019;11. https://doi.org/10.3390/v11100940.

[19] Derrick JL, Gomersall CD. Surgical helmets and SARS infection. Emerg Infect Dis 2004;10:277–9. https://doi.org/10.3201/eid1002.030764.

[20] Wong KC, Leung KS. Transmission and prevention of occupational infections in orthopaedic surgeons. J Bone Joint Surg Am 2004;86:1065–76. https://doi.org/10.2106/00004623-200405000-00029.

[21] Cam Ludwig. Personal protection system Stryker Instrum Memo. http://www.aahks.org/wp-content/uploads/2020/03/coronavirus-stryker-memo.pdf; 2020 [accessed 14.04.20].

[22] Darren Wilstead. Zimmer Biomet's Personal Protection System PPE Communcation. http://www.aahks.org/wp-content/uploads/2020/04/zimmer-ppe-statement.pdf; 2020 [accessed 14.04.20].

[23] Yu X, Yang R. COVID-19 transmission through asymptomatic carriers is a challenge to containment. Influenza Other Respir Viruses 2020. https://doi.org/10.1111/irv.12743.

[24] Lei S, Jiangb F, Sua W, Chend C, Chene J, Meif W, et al. Clinical characteristics and outcomes of patients undergoing surgeries during the incubation period of COVID-19 infection. EClinicalMedicine 2020;5:100331. https://doi.org/10.1016/j.eclinm.2020.100331.

[25] Li D, Wang D, Dong J, Wang N, Huang H, Xu H, et al. False-negative results of real-time reverse-transcriptase polymerase chain reaction for severe acute respiratory syndrome coronavirus 2: role of deep-learning-based CT diagnosis and insights from two cases. Korean J Radiol 2020;21:505–8. https://doi.org/10.3348/kjr.2020.0146.

[26] Xiao AT, Tong YX, Zhang S. False-negative of RT-PCR and prolonged nucleic acid conversion in COVID-19: rather than recurrence. J Med Virol 2020. https://doi.org/10.1002/jmv.25855.

[27] Bartoszko JJ, Farooqi MAM, Alhazzani W, Loeb M. Medical masks vs N95 respirators for preventing COVID-19 in health care workers a systematic review and meta-analysis of randomized trials. Influenza Other Respir Viruses 2020. https://doi.org/10.1111/irv.12745.

[28] Offeddu V, Yung CF, Low MSF, Tam CC. Effectiveness of masks and respirators against respiratory infections in healthcare workers: a systematic review and meta-analysis. Clin Infect Dis 2017;65:1934–42. https://doi.org/10.1093/cid/cix681.

[29] Centers for Disease Control and Prevention. Strategies for optimizing supply of eye protection. https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-strategy/eye-protection.html#conventional-capacity [accessed 12.04.20].

[30] Centers for Disease Control and Prevention. Strategies for optimizing supply of isolation gowns. https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-strategy/isolation-gowns.html [accessed 12.04.20].

[31] Centers for Disease Control and Prevention. Strategies for optimizing supply of facemasks. https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-strategy/face-masks.html [accessed 12.04.20].

[32] Centers for Disease Control and Prevention. Strategies for optimizing the supply of N95 respirators. https://www.cdc.gov/coronavirus/2019-ncov/hcp/respirators-strategy/index.html [accessed 12.04.20].

[33] Centers for Disease Control and Prevention. Decontamination and reuse of filtering facepiece respirators. https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-strategy/decontamination-reuse-respirators.html [accessed 12.04.20].

[34] N95DECON. A scientific consortium for data-driven study of N95 filtering facepiece respirator decontamination. https://www.n95decon.org/ [accessed 12.04.20].