The coronavirus disease (COVID-19) pandemic has posed a challenge for healthcare systems, and healthcare workers (HCWs) are at high risk of exposure. Protecting HCWs is of paramount importance to maintain continuous patient care and keep healthcare systems functioning. Used alongside administrative and engineering control measures, personal protective equipment (PPE) is the last line of defense and the core component of protection. Current data suggest that severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is mainly transmitted through respiratory droplets and close contact. Airborne transmission may occur during aerosol-generating procedures. However, the modes of transmission still remain uncertain, especially regarding the possibility of airborne transmission when aerosol-generating procedures are not performed. Thus, there are some inconsistencies in the respiratory protective equipment recommended by international and national organizations. In Korea, there have been several modifications to PPE recommendations offering options in choosing PPE for respiratory and body protection, which confuses HCWs; they are often unsure what to wear and when to wear it. The choice of PPE is based on the risk of exposure and possible modes of transmission. The level of protection provided by PPE differs based on standards and test methods. Thus, understanding them is the key in selecting the proper PPE. This article reviews evidence on the mode of SARS-CoV-2 transmission, compares the current PPE recommendations of the World Health Organization with those in Korea, and discusses standard requirements and the proper selection of PPE.

Keywords: personal protective equipment; healthcare workers; coronavirus disease (COVID-19); severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2)

INTRODUCTION

Coronavirus disease (COVID-19), which is caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has spread to 216 countries in just a few months. The numbers of cases and deaths have been on the rise since the first case was identified in Wuhan, China in early December 2019 [1]. The COVID-19 pandemic has posed a great challenge for healthcare systems, as the disease has spread explosively, exceeding hospital capacities and placing healthcare workers (HCWs) at high risk of exposure. The proportion of infected
HCWs among confirmed cases was reported to be 10% in Italy and 20% in Spain [2]. In the United States (US), approximately 3% of confirmed cases are HCWs, and 55% of these reported exposure to COVID-19 patients only in healthcare settings [3]. Infected HCWs could also be a source of infection for patients and other HCWs. Protecting HCWs is of paramount importance to maintain continuous patient care and keep healthcare systems functioning.

Measures to prevent transmission of SARS-CoV-2 to HCWs include all levels of hazard control: administrative controls, engineering controls, and personal protective equipment (PPE). Administrative controls include implementing triage, early recognition of suspected patients, source control, providing adequate training for HCWs, monitoring adherence to infection control policies and procedures, and implementing measures to minimize contact with COVID-19 patients (i.e., using telemedicine to initially evaluate suspected patients or designating dedicated HCWs to care only for COVID-19 patients). Engineering controls include placing suspected or confirmed patients in an airborne-infection isolation room, maintaining adequate ventilation, and using physical barriers to prevent transmission between patients and HCWs [4-6]. Along with these control measures, the use of PPE is the last line of defense and a critical component. The choice of PPE is based on the nature of interactions with patients and the modes of transmission [7].

Current data suggest SARS-CoV-2 is transmitted mainly through respiratory droplets and close contact; airborne transmission may be possible during aerosol-generating procedures (AGPs) [8-11]. However, there is still uncertainty surrounding the modes of SARS-CoV-2 transmission, which caused differences in the PPE recommendations of the World Health Organization (WHO) and those of individual countries [12]. In Korea, the first case of COVID-19 was identified on January 20, 2020, and it spread throughout the country. During the initial phase of the pandemic, the government issued guidelines for infection prevention and control in healthcare settings. Selection of appropriate PPE was based on previous guidelines for the Middle East respiratory syndrome (MERS) outbreak in 2015; inconsistencies among these guidelines were also noted. After several updates, the PPE recommendations offered options when choosing PPE for respiratory and body protection. However, selection of optimal PPE is often misinterpreted and misunderstood.

This review discusses the previous and recent evidence on the mode of transmission of respiratory transmissible viruses in conjunction with SARS-CoV-2, the current PPE recommendations in Korea in comparison with those of the WHO and other organizations, and the standard requirements and proper selection of PPE for respiratory and body protection.

**MODE OF TRANSMISSION**

1. **Potential modes of respiratory virus transmission**

In general, respiratory viruses can spread through multiple modes of transmission: contact, respiratory droplets, or aerosols [13]. Contact transmission can occur through direct physical contact with virus-laden respiratory secretions from infected individuals or indirectly through contact with inanimate objects or environments contaminated with the virus [13]. Conventionally, respiratory transmission is classified as either droplet or airborne transmission [4, 7]. It is generally accepted that droplet transmission occurs through deposition of large droplets (>5 µm in diameter) on the mucous membranes (eyes, nose, or mouth) of susceptible people. It occurs when a person is in close proximity to an infected
person, as large droplets travel only short distances (<1 m). Airborne transmission occurs through inhalation of aerosols (≤5 µm in diameter) generated from the respiratory tract of an infected person. Aerosols remain suspended in the air for a prolonged period, allowing them to be transmitted over a long distance [4].

However, mode of transmission cannot be simply dichotomized. There is no clear cut-off to differentiate small and large droplets. Different cutoffs have been suggested based on the area of the respiratory tract where particles deposit (respirable particles <10 µm in diameter penetrating the lower respiratory tract or inspirable particles 10 – 100 µm in diameter depositing in the upper respiratory tract) [14] or based on how they behave (particles <10 µm in diameter suspended in the air or particles >20 µm in diameter that settle fast by gravity) [15]. Particle size is dynamic; it depends on the initial size and composition, the force and pressure at emission, environmental conditions (e.g., temperature, relative humidity and airflow), and the time spent airborne [4]. The distance traveled and the length of time particles remain suspended in the air is also determined by particle size, settling velocity, relative humidity, and airflow [16]. Large droplets settle faster due to gravity, contaminating the near vicinity; some of them can rapidly evaporate to form aerosol particles termed “droplet nuclei,” which behave as other aerosols. Settled droplets may facilitate fomite transmission and can be re-suspended in the air by diverse human activities. Large droplets can also move horizontally for more than 2 meters from the source during coughing or up to 8 meters during sneezing [17]. They can remain suspended for prolonged periods in certain environments, especially where turbulent airflow is abundant, such as in hospital settings where doors open constantly [15]. Particles of varying sizes (0.01 – 500 µm) are produced not only by medical procedures but also by respiratory activities such breathing, speaking, singing, coughing, or sneezing [18-21]. The proportion of aerosol-size particles differs according to the respiratory activities and individuals [21]. As such, it is important to understand that the size of the particles and the resulting behavior follows a continuum; it may overlap either side of this cut-off [21].

However, being airborne does not in itself guarantee effective transmission through aerosols. The virus in aerosols must remain viable in a sufficient quantity to be inhaled by a susceptible host. The virus contained in droplets is subject to biological decay over time, which is affected by the initial metabolic state of the virus, genetic characteristics, and the environment [22, 23]. In this context, the relative contribution of different modes of transmission should be considered, albeit the possibility of airborne transmission does exist. Airborne transmission can be classified as obligate, preferential, or opportunistic. In obligate airborne transmission, transmission occurs only via inhalation of aerosols (e.g., in tuberculosis). Though transmission occurs through multiple routes in preferential airborne transmission, it predominately occurs through aerosols (e.g., in measles, varicella). In opportunistic airborne transmission, the virus is transmitted predominantly through other routes; however, the virus may be transmitted through aerosols under favorable circumstances where aerosols are generated by performing AGPs (e.g., in influenza, SARS-CoV-1 infection) [7, 22, 24].

2. Modes of SARS-CoV-2 transmission

The current consensus regarding the transmission of SARS-CoV-2 is that it is transmitted mainly through respiratory droplets and contact and that airborne transmission is possible during AGPs [9-11, 25]. Although no study has conclusively linked SARS-CoV-2 transmission to contaminated environmental surfaces, indirect contact with fomites is considered a possible route based on the evidence of heavy environmental contamination in healthcare
settings, objects used by COVID-19 patients [26, 27], and the finding that the virus remains viable on plastic surfaces for as long as 3 days [28].

However, there has been controversy whether SARS-CoV-2 can become airborne when AGPs are not performed. Some studies have suggested the potential of airborne SARS-CoV-2 transmission. In one experimental study, viable SARS-CoV-2 was detected in the air for 3 hours when an aerosolized environment was created using a three-jet Collison nebulizer and a Goldberg drum [28]. However, though this experimental condition may simulate circumstances when AGPs are performed, it does not reflect real-life clinical settings. A study in Nebraska detected viral RNA in air samples collected in COVID-19 patient rooms more than 6 feet way from the source patient and in the hallway outside patient rooms, but failed to detect viable virus in air samples [29]. Guo et al. detected SARS-CoV-2 RNA in air samples collected in intensive care units and general wards at a hospital in Wuhan, but the viral RNA was not detected on face shields, in buffer rooms, or in doffing rooms [30]. Liu et al. also found a high concentration of viral RNA in air samples from patients’ toilet areas and staff PPE removal areas in two hospitals in Wuhan, suggesting re-suspension of the virus from contaminated surfaces [31]. However, both studies in Wuhan did not investigate the infectivity of the virus in those air samples. The presence of viral RNA in the air does not necessarily indicate viable virus in sufficient amounts to cause infection, nor does it mean that the virus can effectively be transmitted through this route [11, 32]. Further studies are needed to determine whether it is possible to detect viable SARS-CoV-2 in air samples from patient rooms in which no AGPs are performed and what role it may play in transmission. More importantly, in the study by Liu et al., viral RNA was reduced to undetectable levels in staff PPE removal areas after implementation of rigorous disinfection procedures, which emphasizes the importance of environmental disinfection to prevent the spread of the virus in the perspectives of infection prevention and control. In contrast, other studies have shown that viral RNA was not detected in air samples collected from COVID-19 patient rooms [26], 10 cm away from the patient’s chin [27], or 2-5 meters away from the patient [33]. Transmission did not occur among HCWs wearing surgical masks when they were exposed to a COVID-19 patient, even during endotracheal intubation [34, 35]. No instances of transmission were observed among HCWs caring for COVID-19 patients when they used surgical masks as part of PPE routine care [36].

Based on these findings, it is believed that SARS-CoV-2 is mainly transmitted through droplets and contact, and that airborne transmission is possible under certain circumstances when aerosols are generated during AGPs or support treatment [9, 11]. At the same time, the possibility of airborne transmission should carefully be considered as new evidence emerges.

**CURRENT RECOMMENDATIONS FOR PPE**

In this context, the WHO currently recommends droplet and contact precautions for HCWs caring for COVID-19 patients and airborne precautions for settings where AGPs or support treatment are performed [25]. For droplet precaution, use of medical masks (also referred to as surgical masks) and eye protection (goggles or face shields) is recommended. For contact precaution, long-sleeved water-resistant gowns and gloves are recommended; when AGPs are performed, use of N95, filtering facepiece (FFP)2, FFP3, or equivalent respirators is recommended instead of surgical masks, and additional use of aprons is suggested if gowns are not fluid-resistant [37] (Table 1). However, there are inconsistencies in the
COVID-19 PPE for healthcare workers

Aerosol-generating procedures. PPE recommendations in Canada [38], Australia [39], and the United Kingdom [40] are consistent with those put forth by the WHO. The US Centers for Disease Control and Prevention (CDC) and the European Center for Disease Control and Prevention (ECDC) initially recommended airborne precautions for any situations involving contact with COVID-19 patients; however, they have modified their recommendations to specify that surgical masks are acceptable alternatives if respirators are not available [9, 10]. Despite this difference, airborne precautions are commonly recommended when AGPs are performed (Table 1). Although the transmission risk for HCWs may differ based on procedure being performed [41], AGPs listed in the guidelines generally include endotracheal intubation, bronchoscopy, tracheostomy, cardiopulmonary resuscitation, sputum induction, non-invasive ventilation, manual ventilation, airway suctioning, and nebulizer therapy. In the ECDC guidelines, prone positioning of the patient and disconnecting the patient from a ventilator are also considered AGPs [10, 42]. Surgery or procedures in which high-speed devices are used can also generate aerosols [43]. Although it remains uncertain whether SARS-CoV-2 is transmitted through this route, such procedures may impose substantial transmission risk in dental-clinic settings [44]. Collecting nasopharyngeal/oropharyngeal swabs for SARS-CoV-2 tests can provoke coughing and sneezing, possibly leading to the production of aerosols [9, 10]. However, this procedure requires less time and may pose a less significant risk than other AGPs. For this reason, the recommended respiratory protective equipment for collecting swabs differs

| Settings | KCDC (March 2020) | WHO (April 2020) | CDC (May 2020) | ECDC (May 2020) |
|----------|------------------|------------------|----------------|-----------------|
| Triage: patient examination with direct contact | • KF94 mask or equivalent respirator | - Medical mask | - N95 respirator (or facemask if a respirator is not available) | - Surgical mask or, if available, FFP2 respirator |
| | - Eye protection1 | - Eye protection1 | - Eye protection1 | - Eye protection1 |
| | - Gown2 or coveralls with foot covers | - Gown3 | - Gown3 | - Gown3 |
| | - Gloves | - Gloves | - Gloves | - Gloves |
| Usual inpatient care | • KF94 mask or equivalent respirator | - Medical mask | - N95 respirator (or higher-level respirator) or facemask (if a respirator is not available) | - Surgical mask or, if available, FFP2 respirator |
| | - Eye protection1 | - Eye protection1 | - Eye protection1 | - Eye protection1 |
| | - Gown2 or coveralls with foot covers | - Gown3 | - Gown3 | - Gown3 |
| | - Gloves | - Gloves | - Gloves | - Gloves |
| Aerosol-generating procedures1 | • KF94 mask, equivalent respirator, or PAPR | - N95, FFP2, or FFP3 respirator | - N95 or higher-level respirator | - FFP3 respirator |
| | - Eye protection1 | - Eye protection1 | - Eye protection1 | - Eye protection1 |
| | - Gown2 or coveralls with foot covers | - Gown3 | - Gown3 | - Gown3 |
| | - Gloves | - Gloves | - Gloves | - Gloves |
| | - Apron (if gowns are not fluid-resistant) | - | - | - |
| Collecting specimens (not involving aerosol-generating procedures) | • KF94 mask, equivalent respirator, or PAPR | - Medical mask | - N95 or higher-level respirator (or facemask if a respirator is not available) | - Enclosed spaces:
| | - Eye protection1 | - Eye protection1 | - Eye protection1 | - Surgical mask or, if available, FFP respirator |
| | - Gown2 or coveralls with foot covers | - Gown3 | - Gown3 | - Eye protection1 |
| | - Gloves | - Gloves | - Gloves | - Gown3, gloves |
| | | | | Drive-through or outdoor facilities: |
| | | | | - Surgical mask |

WHO, World Health Organization; CDC, Centers for Disease Prevention and Control; ECDC, European Centers for Disease Prevention and Control; KCDC, Korea Centers for Disease Prevention and Control; PAPR, powered air-purifying respirator; FFP, filtering facepiece.

1Eye protection includes goggles or a face shield.

2Gown refers to a long-sleeved, fluid-resistant gown.

3Aerosol-generating procedures include endotracheal intubation, non-invasive ventilation, tracheostomy, cardiopulmonary resuscitation, manual ventilation, bronchoscopy, open suctioning, sputum induction, nebulizer therapy, etc.

Table 1. Comparisons of personal protective equipment recommendations from the World Health Organization, the US Centers for Disease Prevention and Control (CDC), the European CDC, and Korea CDC [9-10, 37, 47]
among guidelines (Table 1). The Australian and Canadian guidelines emphasize the need for a point-of-care risk assessment to determine the likelihood of exposure based on a patient's symptoms, tasks, and specific environments [38, 45].

In Korea, airborne and contact precautions continue to be recommended in any situations involving any contact with suspected or confirmed patients, with some modifications. Initially, the Korea Center for Disease Control and Prevention (KCDC) guidelines recommended coveralls with shoe covers for contact precautions, goggles/face shields for eye protection, N95 or equivalent respirators for respiratory protection, and powered air-purifying respirators (PAPRs) when AGPs are performed [46]. In the March 2020 revision of these guidelines, long-sleeved water-resistant gowns and KF94 masks were recommended [47]. These modifications may have caused confusion and misunderstanding among HCWs [48]. To select appropriate PPE, it is important to know the differences among respiratory protective equipment (respirators, surgical masks, PAPRs) and protective clothing (coveralls, gowns) and their benefits and drawbacks.

**RESPIRATORY PROTECTION: SURGICAL MASK, FILTERING FACEPIECE RESPIRATOR, AND POWERED AIR-PURIFYING RESPIRATOR**

The main difference between medical masks and respirators is their purpose. Medical masks, also known as surgical masks, are designed to reduce spread of infections from the wearer to others and to protect the wearer's mucous membranes in the nose and mouth from exposure to large respiratory droplets and splashes or sprays of blood or bodily fluids. They are loose-fitting devices not designed to filter small airborne particles [49]. In contrast, respirators are designed to protect the wearers from inhaling hazardous airborne particles by filtering airborne particles (an air-purifying respirator) or supplying clean air to the wearer (an atmosphere-supplying respirator). Air-purifying respirators are further divided into three categories: filtering facepiece respirators (FFRs), elastomeric facepiece respirators, and PAPRs [49]. FFRs, generally known as respirators, are disposable particulate respirators classified in accordance with their filtering efficiency. In healthcare settings, FFRs with at least 95% filtering efficacy, also known as N95 respirators, are commonly used for airborne precautions and need to tightly fit the face to provide proper protection. Other types of air-purifying respirators can be used as alternatives to N95 respirators [49-51].

The WHO has released the Disease Commodity Package (DCP) for COVID-19, a datasheet that lists critical commodities and technical specifications [52]. According to this DCP, surgical masks worn by HCWs should meet the standards of EN 14683 type II, IR, IIR or American Society for Testing and Materials (ASTM) F2100 minimum level 1, or the equivalent, while surgical masks worn by patients (for source control) should meet type I, level 1, or equivalent standards. The following are recommended for FFRs: 1) the minimum N95 respirator according to the Food and Drug Administration (FDA) Class II under 21 CFR 878.4040 and the CDC National Institute for Occupational Safety and Health (NIOSH), 2) the minimum FFP2 respirator according to the EN149, EU PPE regulation 2016/425 Category III, or 3) the equivalent [52]. To choose the proper equipment, it is necessary to understand the standards and requirements to which surgical masks or respirators must conform.
1. Surgical mask

Most surgical masks are composed of three-layers: an outer fluid-repelling layer, a middle layer serving as a high filter, and an inner moisture-absorbing layer. Surgical masks without this three-layer feature cannot provide adequate protection [53]. In the US and Europe, surgical masks are classified as medical devices and regulated accordingly. In the US, five elements are tested to standardize their quality: fluid resistance to synthetic blood, particulate and bacterial filtration efficiency, breathing resistance (pressure drop), flammability, and biocompatibility [54, 55]. In Europe, similar standard requirements have been adopted [56]. Surgical masks are categorized into levels 1, 2, or 3 in the US and I, II, or IIR in Europe (Table 2).

In Korea, however, there are no minimum standards or standardized testing methods to determine the filtering efficiency of surgical masks, and the efficiency of the filters in available surgical masks may vary widely. Fluid resistance to water is the only performance test required for surgical masks in Korea [57]. Fluid resistance reflects only one of the surgical mask’s purposes: to minimize the amount of fluid that could transfer from the outer layers through to the inner layer in cases of splash or spray. However, the surface tension of water is greater than that of blood, and blood can penetrate through fabrics more readily than water [58-59]. The lack of equivalent Korean standards makes it difficult for HCWs to choose appropriate surgical masks as recommended by the WHO. Also, it is difficult to uniformly recommend the use of any surgical mask during care for patients with COVID-19 in Korea unless reliable Korean standards for surgical masks are established. Healthcare facilities should cautiously check whether products meet the standard requirements when procuring surgical masks for HCWs.

2. Filtering facepiece respirators

FFRs are labeled according to their filtering efficiency and the national regulations defining the standard conditions. In the US, there are nine classes of FFRs according to filtration efficacy (95%, 99%, and 99.97%) and the filter’s oil resistance (N, R, and P). N95 respirators filter 95% of airborne particles 0.3 microns in size and are not resistant to oil. They are regulated under NIOSH CFR Part 84 [60]. The European standard (EN149:2001) places FFRs into three classes: FFP1, FFP2, and FFP3 according to their filtering efficiency (80%, 94%, and 99%, respectively) [61, 62]. As the Korean standards follow the European standards, FFRs manufactured in Korea are classified similarly: KF80, KF94, and KF99 (Table 3) [62, 63]. FFP2/3 and KF94/99 respirators are used for HCWs. In addition to a filtering efficiency test, a breathing resistance test (pressure drop) is required. Pressure drop is an objective measure of breathability; a high pressure drop indicates more difficulty in breathing. KF94 and FFP2 respirators require ≤70 Pa at an airflow rate of 30 L/min, whereas N95 respirators

---

**Table 2. Comparison of the standard requirements for surgical masks in the US and Europe [55]**

| Test                              | The US ASTM F2100-19 | Europe EN 14683:2019 |
|-----------------------------------|-----------------------|-----------------------|
|                                   | Level 1               | Level 2               | Level 3               | Type I   | Type II  | Type IIR |
| Bacterial filtration efficiency (%) | ≥95                   | ≥98                   | ≥98                   | ≥95      | ≥98      | ≥98      |
| Particulate filtration efficiency (%) | ≥95                   | ≥98                   | ≥98                   | Not required | Not required | Not required |
| Fluid resistance to synthetic blood | Pass at 80 mmHg       | Pass at 120 mmHg      | Pass at 160 mmHg      | Not required | Not required | Pass at ≥16.0 kPa (>120 mmHg) |
| Differential Pressure              | <5.0 mmHg/cm²         | <6.0 mmHg/cm²         | <6.0 mmHg/cm²         | <40 Pa/cm² | <40 Pa/cm² | <60 Pa/cm² |
| Microbial Cleanliness              | Not required           | Class I               | Not required           | Not required | <30 CFU/g |
| Flammability                       |                        |                       |                        |           | Not required |
| Biocompatibility                   |                       |                       |                        | S10 K Guidance recommends testing to ISO 10993 | Complete an evaluation according to ISO 10993 |

US, United States; CFU, colony-forming unit; ASTM, American Society for Testing and Materials; ISO, international organization for standardization.
require ≤343 Pa at 85 L/min. Since pressure drop increases with the flow rate, standard pressure drop requirements are similar, even though they appear different \cite{64,65}. In Korea and Europe, total inward leakage (TIL) is also tested on human subjects (Table 3) \cite{62}. In the US, the TIL test is not performed. Instead, fit testing must be performed prior to working in the environment where wearing a respirator is required and be repeated annually under the Occupational Safety and Health Administration (OSHA) regulation 1910.134 \cite{66}. Despite differences in test methods, it is generally considered that US N95, EU FFP2, and KF94 respirators are equivalent for filtering non-oil based airborne particles \cite{64,65,67}.

However, concerns have been raised because the fit test is not regularly performed in many Korean hospitals, despite the Korea OSHA recommending a fit test for wearers every year \cite{68,69}. Respirators must fit the face tightly for effective filtering of airborne particles. Noti et al. demonstrated that a poorly-fitting N95 respirator was not as effective as a tightly fitting respirator at blocking infectious viruses (66.5% vs. 99.6% blocked, respectively) and performed no better than unsealed surgical masks (66.5% vs. 56.6% blocked, respectively) in a simulation experiment \cite{70}. In Korea, the TIL test is performed on ten human subjects doing five types of exercise \cite{63}. This TIL test can eliminate respirators that are inherently poorly-fitting and that do not comply with this requirement or identify that the tested respirator is generally well-fitting. However, fitting is affected by a wearer’s face shape and size, age, and gender, as well as the respirator design \cite{71,72}. Fit testing helps to select a respirator model that fits an individual’s face well enough to provide at least the assigned protection factor of 10 \cite{73}. Fit performance was also found to vary by respirator model, ranging from fitting less than 5% to those fitting 95% of the test subjects \cite{71}. In addition to the model type, ear-loop designs appear to be less effective in achieving a proper fit than head-band designs \cite{67}. This is worrisome, since most KF94 masks have ear loops. As AGPs may put HCWs at an increased risk for virus exposure and infection, the design of KF94 masks limits their use during AGPs. KF94 masks of various shapes and sizes and with elastic head-band designs should be offered to HCWs to improve the fitting of the masks. A recent study on the current status of fit testing in Korea showed that 82% of 52 HCWs failed to meet the criteria of fit factor 100, even when using N95 respirators \cite{68}. Considering these findings, HCWs should be fit-tested for FFRs, regardless of their labels (KF94, N95, or FFP2) to ensure respiratory protection. Though it is challenging and laborious for hospitals to implement fit testing practices for all HCWs in the midst of the COVID-19 pandemic, protecting HCWs is of paramount importance.

Even so, fit testing alone does not guarantee respiratory protection \cite{74}. Inappropriate donning and skipping the self-seal-check after donning an FFR were found to be frequent.

### Table 3. Comparison of respirator approval standards for KF masks and FFP respirators \cite{62,63}

| Filtering efficiency (%) | Test agent | Inhalation resistance - pressure drop (flow rate) | Total inward leakage* (%) |
|--------------------------|------------|--------------------------------------------------|---------------------------|
| **Korea**                |            |                                                  |                           |
| KF80                     | 80         | NaCl                                             | ≤60 (at 30 L/min)         | 25            |
| KF94                     | 94         | NaCl & paraffin oil                              | ≤70 (at 30 L/min)         | 11            |
| KF99                     | 99         | NaCl & paraffin oil                              | ≤100 (at 30 L/min)        | 5             |
| **Europe**               |            |                                                  |                           |
| FFP1                     | 80         | NaCl & paraffin oil                              | ≤60 (at 30 L/min), ≤210 (at 95 L/min) | 22b          |
| FFP2                     | 94         | NaCl & paraffin oil                              | ≤70 (at 30 L/min), ≤240 (at 95 L/min) | 8b           |
| FFP3                     | 99         | NaCl & paraffin oil                              | ≤100 (at 30 L/min), ≤300 (at 95 L/min) | 2b           |

FPP, filtering facepiece.

*At least 46 of the 50 individual exercise results (10 subjects x 5 exercises) for total inward leakage shall not be greater than the requirements. b For European standards, at least 8 out of 10 individual wearers’ arithmetic means for total inward leakage shall not be greater than the requirements as well.
causes of improper fit [68, 74]. Since training on the proper use of FFRs can improve fitting of the respirators among HCWs [74, 75], training programs should be implemented along with fit testing.

The risk of exposure to blood or bodily fluids should also be considered when selecting the proper FFRs, because most FFRs are not water-resistant. To protect HCWs against the splash/spray of blood or bodily fluids as well as airborne particles (i.e., during an operation on a patient with COVID-19), surgical respirators with fluid resistance properties should be used [49]. A surgical N95 respirator, which is approved by the NIOSH as an FFR and the FDA as a surgical mask, is one example.

3. Powered air purifying respirator

PAPRs are increasingly used as an alternative to N95 respirators. PAPRs use a battery-powered fan to force air through a filter, cartridge, or canister to a tight-fitting facepiece or loose-fitting hood [49]. Loose-fitting PAPRs are commonly used in healthcare settings, as they have several advantages: higher respiratory protection with an assigned protection factor of 25 (as compared to 10 for N95 respirators), a barrier against splash, and less difficulty in breathing. They are also reusable, and do not require fit testing [50, 76].

However, there are disadvantages to PAPRs use: They are heavy, may impede HCWs’ ability to care for patients, limit communication due to noise, require batteries to be recharged or replaced, and take up significant storage space [76]. Although a fit test is not required, they do need to be properly sized, as protection can decrease with oversized or stretched-out PAPRs [77]. Another disadvantage is that the wearer’s exhaled air is unfiltered, which limits the use of PAPRs in close proximity to sterile fields [50, 76]. More importantly, risk of contamination during doffing procedures is high, requiring HCWs to receive special training and assistance in the doffing process. Cleaning and disinfection must be performed between uses. This process must be thorough and performed by trained individuals.

Loose-fitting PAPRs are suitable when AGPs are frequently performed (such as in intensive care unit settings), when HCWs are not able to wear tight-fitting FFRs, or when the fitting of a FFR may be compromised. For safe use, healthcare facilities should be aware of the advantages and disadvantages associated with PAPRs. They must also establish a robust maintenance program, including HCW training for proper PAPR use and the cleaning and disinfection process prior to the use of PAPRs [76, 78].

4. The comparative effectiveness of N95 respirators and surgical masks in preventing respiratory viral infections

Infectious aerosol particles are produced by diverse respiratory activities, including speaking and breathing [79-80]. HCWs in close proximity to patients with COVID-19 are at risk of short-range airborne transmission as well as large-droplet transmission [81]. As such, there have been debates regarding the effectiveness of surgical masks against the virus in routine patient care, and use of N95 respirators or the equivalent is often advocated [82]. However, no clinical trial has compared the effectiveness of surgical masks and N95 respirators in preventing COVID-19 among HCWs. Based on the systematic review of five observational studies on HCWs, wearing any mask (surgical mask or N95 respirator) reduced the risk of developing respiratory infection (odds ratio [OR] for surgical masks, 0.13; 95% confidence interval [CI], 0.03 – 0.62 vs. OR for N95 respirators, 0.12; 95% CI, 0.05 – 0.26) [83]. A recent randomized clinical trial in the US demonstrated no significant difference in the incidence
of laboratory confirmed influenza between outpatient HCWs wearing surgical masks and those wearing N95 respirators [84]. Two meta-analyses, which were separately performed by different research groups, reached the same conclusion: Surgical masks and N95 respirators offer similar protection against respiratory viral infection among HCWs during non-aerosol-generating care [85, 86]. Based on these findings, the Infectious Disease Society of America recommends that HCWs caring for patients with suspected or confirmed COVID-19 use either a surgical mask or N95 (or N99 or PRPR) respirator and that HCWs involved in AGPs use N95 or higher-level respirators [83]. Chu et al. investigated the effectiveness of face masks in preventing transmission of SARS, MERS, or COVID-19 in healthcare and non-healthcare settings by analyzing 44 observational studies. They found that the use of face masks (12 – 16-layer cotton masks, surgical masks, N95, or similar respirators) resulted in a large reduction of infection risk in healthcare settings (relative risk [RR], 0.30; 95% CI, 0.22 – 0.41). N95 or similar respirators had a stronger protective association (RR, 0.04; 95% CI, 0.004 – 0.30) than surgical masks or 12 – 16-layer cotton masks (RR, 0.33; 95% CI, 0.17 – 0.61), and both N95 and surgical masks had a strong association with protection when compared to single-layer masks [87]. The review, however, included only four studies comparing N95 or similar respirators with no mask, and two of them involved situations in which AGPs were performed. Based on this review alone, it is difficult to generalize that the use of N95 or similar respirators provides more protection during routine care for patients with COVID-19. Therefore, the use of N95, FFP2, or higher-level respirators such as PAPRs should be prioritized when AGPs are performed. It is also necessary to vigilantly monitor situations or procedures that may increase the possibility of aerosol transmission, because many of the characteristics of SARS-CoV-2 remain unknown.

**PROTECTIVE CLOTHING: GOWNS VS. COVERALLS**

The choice of protective clothing should be based on a thorough risk assessment of potential exposure to blood and body fluids and transmission modes. The risk of exposure may depend on the stage of the disease, the severity of symptoms, and the types of procedures conducted. Once the risks are assessed, selection can be guided by the type of barrier, design, critical properties such as seams/closures, and donning and doffing features of the clothing.

The WHO, CDC, and ECDC recommend the use of long-sleeved water-resistant gowns and gloves when caring for COVID-19 patients. In its recent publication on the rational use of PPE, the WHO also specifies situations in which gowns should be donned. According to the WHO DCP for COVID-19, EN 13975, any performance level gowns or Association for the Advancement of Medical Instrumentation (AAMI) PB70, all level or equivalent gowns are acceptable [52]. Regarding coveralls as PPE against COVID-19, the WHO stated they are neither required nor generally recommended, and the CDC recommends them as an alternative in contingency situations. On the other hand, in Korea, initial recommendations recommended only coveralls for body protection; the guidelines were subsequently changed to specify that either gowns or coveralls can be used. This may cause confusion among frontline HCWs regarding what kind of protective clothing should be chosen. Moreover, there is no national standard for HCW protective clothing in Korea. Therefore, it is necessary to understand the relevant international standards and test methods to select and procure the proper protective clothing.

In the US, surgical and isolation gowns are medical devices subjected to regulation. ANSI/AAMI PB70 classifies surgical gowns and isolation gowns into 4 levels (level 1 being the
As there are various performance levels of gowns and coveralls, it cannot be simply concluded that one is more protective than the other. The specific barrier properties should be thoroughly reviewed, and protective clothing appropriate for specific diseases should be selected accordingly. For example, for Ebola virus disease, which is mainly transmitted through contact with blood or bodily fluids, gowns and coveralls should be resistant to penetration by blood and any bodily fluids or by blood-borne pathogens and compliant with the corresponding standards. Fluid-resistant protective clothing includes ANSI/AAMI PB70

Table 4. Comparison of barrier performance of surgical and isolation gowns according to ANSI/AAMI PB70 and EN 13795 standards [59, 89]

| Classification | ANSI/AAMI PB70 Testing | EN 13795 Classification | EN 13795 Testing |
|---------------|-------------------------|-------------------------|------------------|
| Low risk      |                         |                         |                  |
| Level 1       | AATCC 42 - Water penetration ≤1.0 g | Low performance | EN 20811 - Hydrostatic pressure ≥10 cm (less critical areas) & ≥100 cm (critical areas) |
|               |                         |                         | EN ISO 22612 - EN ISO 22612 - Resistance to microbial penetration, dry ≤300 (less critical areas) |
| Minimal water resistance: some resistance to water spray | AATCC 42 - Water penetration ≤1.0 g | EN ISO 22612 Resistance to microbial penetration, wet ≥12.8 I_B (critical areas) |
| Level 2       | AATCC 127 - Hydrostatic pressure ≥20 cm water column |                         |                  |
| Minimal water resistance: some resistance to water spray |                         |                         |                  |
| Level 3       |                         |                         |                  |
| High risk     |                         |                         |                  |
| Level 4       | AATCC 42 - Water penetration ≤1.0 g | High performance | EN 20811 - Hydrostatic pressure ≥10 cm (less critical areas) & ≥100 cm (critical areas) |
| Moderate water resistance: resistant to water spray and some resistance to water penetration under constant contact with increasing pressure | AATCC 127 - Hydrostatic pressure ≥50 cm water column | EN ISO 22612 - EN ISO 22612 - Resistance to microbial penetration, dry ≤300 (less critical areas) |
| Blood and viral penetration resistance | ASTM F1670 (Blood) & ASTM F1671 (Viral): No penetration at 13.8 kPa | EN ISO 22612 Resistance to microbial penetration, wet ≥6.0 I_B (critical areas) |

ANSI, American National Standards Institute; AAMI, Association for the Advancement of Medical Instrumentation; AATCC, American Association of Textile Chemists and Colorists; ISO, International Organization for Standardization; ASTM, American Society for Testing and Materials. AATCC 42 Water resistance: impact penetration test determines the ability of a material to resist water penetration under spray impact; AATCC 127 Water resistance: hydrostatic pressure test determines the ability of a material to resist water penetration under constant contact with increasing pressure; ASTM F1670 Synthetic blood penetration tests determine the ability of a material to resist the penetration of synthetic blood under constant contact; ASTM F1671 Viral penetration tests determine the ability of a material to resist the penetration of a microorganism under constant contact. EN 20811 evaluates a fabric's resistance to water penetration under constantly increasing hydrostatic pressure. The EN ISO 22612 test evaluates a dry fabric's ability to resist penetration of particles carrying microorganisms. The EN ISO 22610 test evaluates a fabric's resistance to microbial penetration under conditions of liquid pooling on the fabric and mechanical rubbing. Test results are expressed in I "Barrier Index." I=6.0 indicates no penetration.
level 3 or EN 13795 high performance gowns and coveralls made of fabrics passing tests using ASTM 1670 (13.8 kPa), ISO 16603 class 3, or higher pressure (≥3.5 kPa). Protective clothing resistant to blood-borne pathogen penetration includes ANSI/AAMI level 4 gowns or coveralls made of fabric passing tests using ASTM F1671 (13.8 kPa), ISO 16604 class 2, or higher pressure (≥1.75 kPa) [90]. For COVID-19, any water-resistant level gowns are acceptable [52]. Thus, the proper level of gown protection should be chosen based on the risk assessment of exposure, the pressure and type of contact, as well as the duration and type of procedure [91].

No study has compared the effectiveness of gowns and coveralls in reducing transmission of the virus to HCWs, and gowns and coveralls are generally considered acceptable and effective [59, 92]. One of the major differences is the design. Coveralls are designed to cover the whole body, including the back and lower legs, while gowns do not provide continuous whole body protection. When wearing gowns, protection of the back area can be compromised depending on the activities of HCWs, such as squatting or sitting down, so sufficient overlap of fabric is necessary to cover the back. On the other hand, barrier protection can be compromised when using coveralls with a front zipper closure not covered with a flap of barrier material because seam barrier properties are essential for protection [59]. Gowns are easier to don and doff, and they are more likely to be used correctly as HCWs are relatively more familiar with gowns than with coveralls. In contrast, coveralls are difficult to doff, and the risk of self-contamination can be higher during the doffing process [59, 93-97].

HCWs should be trained properly and should practice the use of coveralls before using them during patient care. Moreover, coveralls generate more heat stress than do gowns, which leads to discomfort, fatigue, and dehydration. Considering these differences, the decision of which of the two to use should be based on availability, HCW activities, and the physical characteristics of the work environment [59].

In summary, current data suggest that SARS-CoV-2 is primarily transmitted through respiratory droplets and close contact. Airborne transmission may occur during AGPs in healthcare settings. PPE for droplet and contact precautions, such as surgical masks with eye protection, gowns, and gloves, are recommended for HCWs in contact with suspected or confirmed COVID-19 patients, and N95 or equivalent respirators should to be worn by HCWs whenever AGPs are performed. Although droplets and close contact are the main modes of SARS-CoV-2 transmission, selection of the proper PPE should be based on a thorough risk assessment of the extent and duration of exposure and the properties of the PPE required for protection. Degrees of respiratory protection and barrier properties differ according to various standards and test methods. Therefore, it is important to understand the national or international standards for respiratory protective equipment and protective clothing, and PPE certified to provide effective protection against SARS-CoV-2 should be chosen. Healthcare facilities must check the specifications of products thoroughly before procuring them. It is also important to ensure that HCWs are well trained for the proper use of PPE, because appropriate donning and doffing is essential for proper protection. The overuse of PPE can lead to supply shortages when high levels of protection must be used, potentially exposing HCWs to greater risk of infection. Therefore, PPE should be appropriately selected and rationally used. It should be noted that PPE is the last line of protection and its use alone does not effectively reduce transmission risk. Effective administrative and engineering controls, including early identification of suspected patients and source control, must be implemented simultaneously. Furthermore, basic infection prevention measures, such as frequent hand washing and rigorously disinfecting the environment, must be
emphasized. As the occurrence of airborne transmission when AGPs are not performed remains uncertain, PPE recommendations are subject to change in accordance with future study results. Healthcare facilities and HCWs should be vigilantly aware of such changes in recommended PPE and prepare for the future.

REFERENCES

1. World Health Organization (WHO). WHO coronavirus disease (COVID-19) dashboard (2020/6/6). Available at: https://covid19.who.int/. Assessed 20 May 2020.

2. European Center for Disease Control and Prevention (ECDC). Coronavirus disease 2019 (COVID-19) in the EU/EEA and the UK – ninth update, 23 April 2020. Stockholm: ECDC; 2020.

3. CDC. Covid-19 Response Team. Characteristics of health care personnel with COVID-19 - United States, February 12-April 9, 2020. MMWR, Morb Mortal Wkly Rep 2020;69:477-81. PUBMED | CROSSREF

4. World Health Organization (WHO). The WHO guidelines Infection prevention and control of epidemic- and pandemic-prone acute respiratory infections in health care. Geneva: WHO; 2014.

5. Centers for Disease Control and Prevention (CDC). Coronavirus disease 2019 (COVID-19); N95 respirators. Available at: https://www.cdc.gov/coronavirus/2019-ncov/hcp/respirators-strategy/index.html. Assessed 1 June 2020.

6. Koo BK, Bang IH, Kim SY, Kim EJ, Park SW. Glove-wall system for respiratory specimen collection and COVID-19 mass screening. Infect Chemother 2020. [Epub ahead of print]. PUBMED

7. Siegel JD, Jackson M, Chiarello L; Healthcare Infection Control Practices Advisory Committee. 2007 Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings. 2007. Available at: http://www.american HospitalAssociation.org/IAC/Isolation2007.pdf. Accessed 1 June 2020.

8. World Health Organization (WHO). Infection prevention and control during health care when COVID-19 is suspected: interim guidance, 19 March 2020. Available at: https://apps.who.int/iris/handle/10665/331495. Accessed 1 June 2020.

9. Centers for Disease Control and Prevention (CDC). Interim infection prevention and control recommendations for patients with suspected or confirmed coronavirus disease 2019 (COVID-19) in healthcare settings (Update May 18, 2020). Available at: https://www.cdc.gov/coronavirus/2019-ncov/hcp/infection-control-recommendations.html. Assessed 1 June 2020.

10. European Center for Disease Control and Prevention (ECDC). Infection prevention and control for COVID-19 in healthcare settings – 3rd update. 13 May 2020. Stockholm: ECDC; 2020.

11. World Health Organization (WHO). Modes of transmission of virus causing COVID-19: implications for IPC precaution recommendationsscientific brief, 29 March 2020. Available at: https://apps.who.int/iris/handle/10665/331616. Assessed 1 June 2020.

12. Zhang JC, Cram P, Adisesh A. Controversies in respiratory protective equipment selection and use during COVID-19. J Hosp Med 2020;15:292-4. PUBMED | CROSSREF

13. Otter JA, Donskey C, Yezli S, Douthwaite S, Goldenberg SD, Weber DJ. Transmission of SARS and MERS coronaviruses and influenza virus in healthcare settings: the possible role of dry surface contamination. J Hosp Infect 2016;92:235-50. PUBMED | CROSSREF

14. Institute of Medicine (IOM). Preventing transmission of pandemic influenza and other viral respiratory diseases: personal protective equipment for healthcare personnel. Washington, DC: National Academies Press; 2011.

15. Tellier R, Li Y, Cowling BI, Tang JW. Recognition of aerosol transmission of infectious agents: a commentary. BMC Infect Dis 2019;19:101. PUBMED | CROSSREF

16. Xie X, Li Y, Chwang AT, Ho PL, Seto WH. How far droplets can move in indoor environments--revisiting the Wells evaporation-falling curve. Indoor Air 2007;17:211-25. PUBMED | CROSSREF

17. Bahl P, Doolan C, de Silva C, Chuhtai AA, Bourouiba L, MacIntyre CR. Airborne or droplet precautions for health workers treating COVID-19? J Infect Dis 2020. [Epub ahead of print]. PUBMED | CROSSREF
18. Lindsley WG, Blachere FM, Davis KA, Pearce TA, Fisher MA, Khakoo R, Davis SM, Rogers ME, Thewlis RE, Posada JA, Redrow JB, Celik IB, Chen BT, Beezhold DH. Distribution of airborne influenza virus and respiratory syncytial virus in an urgent care medical clinic. Clin Infect Dis 2010;50:693-8.

19. Lindsley WG, Blachere FM, Thewlis RE, Vishnu A, Davis KA, Cao G, Palmer JE, Clark KE, Fisher MA, Khakoo R, Beezhold DH. Measurements of airborne influenza virus in aerosol particles from human coughs. PLoS One 2010;5:e15100.

21. Anfinrud P, Stadnytskyi V, Bax CE, Bax A. Visualizing speech-generated oral fluid droplets with laser light scattering. N Engl J Med 2020;382:2061-3.

22. Roy CJ, Milton DK. Airborne transmission of communicable infection--the elusive pathway. N Engl J Med 2004;350:1710-2.

23. Tang JW, Li Y, Eames I, Chan PK, Ridgway GL. Factors involved in the aerosol transmission of infection and control of ventilation in healthcare premises. J Hosp Infect 2006;64:100-14.

24. Seto WH. Airborne transmission and precautions: facts and myths. J Hosp Infect 2015;89:225-8.

25. World Health Organization (WHO). Infection prevention and control during health care when novel coronavirus (nCoV) infection is suspected: interim guidance. (19 March 2020). Available at: https://www.who.int/publications/i/item/10665-331495. Assessed 1 June 2020.

27. Cheng VCC, Wong SC, Chen JHK, Yip CCY, Chuang VWM, Tsang OTY, Sridhar S, Chan JFW, Ho PL, Yuen KY. Escalating infection control response to the rapidly evolving epidemiology of the coronavirus disease 2019 (COVID-19) due to SARS-CoV-2 in Hong Kong. Infect Control Hosp Epidemiol 2020;41:493-8.

28. Santarpia JL, Rivera DN, Herrera V, Morwitzer MJ, Creager H, Santarpia GW, Crown KK, Brett-Major DM, Schnaubelt E, Broadhurst MJ, Lawler IV, Reid SP, Lowe JJ. Transmission Potential of SARS-CoV-2 in Viral Shedding Observed at the University of Nebraska Medical Center. Available at: https://www.medrxiv.org/content/10.1101/2020.03.23.20039446v2.full.pdf. Accessed 21 May 2020.

31. Liu Y, Ning Z, Chen Y, Guo M, Liu Y, Gali NK, Sun L, Duan Y, Cai J, Westerdahl D, Liu X, Xu K, Ho KF, Kan H, Fu Q, Lan K. Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals. Nature 2020. [Epub ahead of print].

32. National Academies of Sciences, Engineering, and Medicine. Rapid Expert Consultations on the COVID-19 Pandemic: March 14, 2020-April 8, 2020. Washington, DC: National Academis Press; 2020.

33. Faridi S, Niazi S, Sadeghi K, Naddafi K, Yavarian J, Shamsipour M, Jandaghi NZS, Sadeghniat K, Nabizadeh R, Yunesian M, Momeniha F, Mokamel A, Hassanvand MS, MokhtariAzad T. A field indoor air measurement of SARS-CoV-2 in the patient rooms of the largest hospital in Iran. Sci Total Environ 2020;725:138401.

34. Wong SCY, Kwong RTS, Wu TC, Chan IWM, Chu MY, Lee SY, Wong HY, Lung DC. Risk of nosocomial transmission of coronavirus disease 2019: an experience in a general ward setting in Hong Kong. J Hosp Infect 2020;105:119-27.
35. Canova V, Lederer Schläpfer H, Piso RJ, Droll A, Fenner L, Hoffmann T, Hoffmann M. Transmission risk of SARS-CoV-2 to healthcare workers -observational results of a primary care hospital contact tracing. Swiss Med Wkly 2020;150:w20257.

36. World Health Organization (WHO). WHO "SAVE LIVES: Clean Your Hands" Campaign and WHO COVID-19 Response: WHO webinar series. Available at: https://www.who.int/infection-prevention/campaigns/clean-hands/webinars_slcyh2020.pdf?ua=1. Accessed 1 June 2020.

37. World Health Organization (WHO). Rational use of personal protective equipment for coronavirus disease (COVID-19) and considerations during severe shortages: interim guidance, 6 April 2020. Available at: https://apps.who.int/iris/handle/10665/331695. Accessed 1 June 2020.

38. Government of Canada. Infection prevention and control for COVID-19: second interim guidance for acute healthcare settings. Available at: https://www.canada.ca/en/public-health/services/diseases/2019-novel-coronavirus-infection/health-professionals/infection-prevention-control-covid-19-second-interim-guidance.html. Assessed 1 June 2020.

39. Australian Government Department of Health. Guidance on the use of personal protective equipment (PPE) in hospitals during the COVID-19 outbreak (last update 27 May 2020). Available at: https://www.health.gov.au/resources/publications/guidance-on-the-use-of-personal-protective-equipment-ppe-in-hospitals-during-the-covid-19-outbreak. Accessed 1 June 2020.

40. Public Health England (PHE). COVID-19: Guidance for infection prevention and control in healthcare settings. Version 3.0. Available at: https://www.gov.uk/government/publications/wuhan-novel-coronavirus-infection-prevention-and-control. Accessed 1 June 2020.

41. 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.

42. Alhazzani W, Møller MH, Arabi YM, Loeb M, Gong MN, Fan E, Oczkowski S, Levy MM, Derde L, Dzierba A, Du B, Aboditi M, Wunsch H, Cecconi M, Koh Y, Chertow DS, Maitland K, Alshamsi F, Belley-Cote E, Greco M, Laundy M, Morgan JS, Kescicioglu J, McGeer A, Mermel L, Mammen MJ, Alexander PE, Arrington A, Centofanti JE, Citerio G, Baw B, Memish ZA, Hammond N, Hayden FG, Evans I, Rhodes A. Surviving sepsis campaign: guidelines on the management of critically ill adults with Coronavirus Disease 2019 (COVID-19). Intensive Care Med 2020;46:854-87.

43. Judson SD, Munster VI. Nosocomial transmission of emerging viruses via aerosol-generating medical procedures. Viruses 2019;11:940.

44. Centers for Disease Control and Prevention (CDC). Interim infection prevention and control guidance for dental settings during the COVID-19 response. Available at: https://www.cdc.gov/coronavirus/2019-ncov/hcp/dental-settings.html. Assessed 1 June 2020.

45. Australian Government Department of Health. Interim advice on non-inpatient care of persons with suspected or confirmed Coronavirus disease (COVID19), including use of personal protective equipment (PPE). Available at: https://www.health.gov.au/sites/default/files/documents/2020/03/interim-advice-on-non-inpatient-care-of-persons-with-suspected-or-confirmed-coronavirus-disease-2019-covid-19-including-use-of-personal-protective-equipment-ppe.pdf. Accessed 1 June 2020.

46. Korea Center for Disease Control and Prevention (KCDC). Ministry of Health and Welfare. Infection prevention and control for novel coronavirus infection (February 2020). Available at: https://cheongju.go.kr/www/selectBbsNttView.do?key=280&bbsNo=510&nttNo=145181&integrDeptCode=000100101. Accessed 1 June 2020.

47. Korea Center for Disease Control and Prevention (KCDC). Press release on full body protective clothing. Available at: http://ncov.mohw.go.kr/tcmBoardView.do?brdId=145&brdGubun=&dataGubun=&ncvContSeq=353210&contSeq=353210&board_id=145&gubun=BDH. Accessed 1 June 2020.

48. Korea Center for Disease Control and Prevention (KCDC). Coronavirus disease 2019 (COVID-19). Powered air purifying respirators: For healthcare practitioners (HCP). Available at: https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-strategy/powered-air-purifying-respirators-strategy.html. Accessed 1 June 2020.
51. Centers for Disease Control and Prevention (CDC). Coronavirus disease 2019 (COVID-19). Elastomeric respirators: Conventional, contingency, and crisis strategies. Available at: https://www.cdc.gov/coronavirus/2019-ncov/hcp/elastomeric-respirators-strategy/index.html. Assessed 1 June 2020.

52. World Health Organization (WHO). COVID-19 v4: operational support and logistics: disease commodity packages. Available at: https://apps.who.int/iris/handle/10665/331434. Accessed 1 June 2020.

53. Center for Health Protection. Use mask properly. Available at: https://www.chp.gov.hk/en/features/102742.html. Assessed 1 June 2020.

54. Food and Drug Administration (FDA). Surgical masks - Premarket notification [510(k)] submissions: guidance for industry and FDA staff. Available at: https://www.fda.gov/regulatory-information/search-fda-guidance-documents/surgical-masks-premarket-notification-510k-submissions. Accessed 1 June 2020.

55. American Society for Testing and Materials (ASTM) International. Standard Specification for Performance of Materials Used in Medical Face Masks. 2019. Available at: https://www.astm.org/READINGLIBRARY/VIEW/F2100.html. Assessed 1 June 2020.

56. Carlos Rubio-Romero J, Del Carmen Pardo-Ferreira M, Antonio Torrecilla García J, Calero-Castro S. Disposable masks: Disinfection and sterilization for reuse, and non-certified manufacturing, in the face of shortages during the COVID-19 pandemic. Saf Sci 2020;129:104830.

57. National Institute of Food and Drug Safety Evaluation (NIFDS). Guideline on establishment of test item in preparation of standards and analytical methods of quasi-drugs (August 2016). Ministry of Food and Drug Safety. 2017. Available at: https://www.nifds.go.kr/brd/m_15/view.do?seq=11936. Assessed 1 June 2020.

58. Hrnčír E, Rosina J. Surface tension of blood. Physiol Res 1997;46:319-21.

59. Centers for Disease Control and Prevention (CDC). The National Personal Protective Technology Laboratory (NPPTL). Considerations for selecting protective clothing used in healthcare for protection against microorganisms in blood and body fluids. Available at: https://www.cdc.gov/niosh/npptl/topics/protectiveclothing/default.html. Assessed 1 June 2020.

60. Centers for Disease Control and Prevention (CDC). The National Institute for Occupational Safety and Health (NIOSH). 42 CFR part 84 respiratory protective devices. Available at: https://www.cdc.gov/niosh/npptl/topics/respirators/pt84abs2.html. Accessed 1 June 2020.

61. Coia JE, Ritchie L, Adisesh A, Makison Booth C, Bradley C, Bunyan D, Carson G, Fry C, Hoffman P, Jenkins D, Phin N, Taylor B, Nguyen-Van-Tam JS, Zuckerman M; Healthcare Infection Society Working Group on Respiratory and Facial Protection. Guidance on the use of respiratory and facial protection equipment. J Hosp Infect 2013;85:170-82.

62. Han DH. Usage of filtering-facepiece masks for healthcare workers and importance of fit testing. J Korean Soc Occup Environ Hyg 2015;25:245-53.

63. National Institute of Food and Drug Safety Evaluation (NIFDS). Guidelines for standards of health masks (civil complaints guide). Ministry of Food and Drug Safety. 2019. Available at: http://www.nifds.go.kr/brd/m_15/view.do?seq=12791&srchFr=&srchTo=&srchWord=&srchTp=&itm_seq_1=0&itm_seq_2=0&multi_itm_seq=0&company_cd=&company_nm=&page=6. Assessed 1 June 2020.

64. Jung H, Kim JK, Lee S, Lee J, Kim J, Tsai P, Yoon C. Comparison of filtration efficiency and pressure drop in anti-yellow sand masks, quarantine masks, medical masks, general masks, and handkerchiefs. AEROSOL AIR. Qual Res 2014;14:991-1002.

65. 3M. Technical bulletin: Comparison of FFP2, KN95, and N95 and other filtering facepiece respirator Classes. May 2020. Available at: https://multimedia.3m.com/mws/media/1791500O/comparison-ffp2-kr95-n95-filtering-facepiece-respirator-classes-tb.pdf. Accessed 1 June 2020.

66. United States Department of Labor. Occupational Safety and Health Act. 29CFR 1910.134. Respiratory protection, 2011. Available at: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.134. Assessed 1 June 2020.

67. Centers for Disease Control and Prevention (CDC). The National Personal Protective Technology Laboratory (NPPTL). NPPTL respirator assessments to support the COVID19 response. Available at: https://www.cdc.gov/niosh/npptl/respirators/testing/default.html. Assessed 1 June 2020.

68. Han DH, Kim HW, Jang YJ, Myong JP, Yang HS, Seo HK, Kim JH, Jang GM, Park KH, Lee YJ, Sung YJ, Kawashalya MR. A study on the current status and system improvement of the respiratory protection test. Ulsan: Korea Occupational Safety and Health Agency; 2017.

69. Korea Occupational Safety and Health Administration (KOSHA). Guide to respiratory protection. 2015. Available at: http://www.kosha.or.kr/kosha/data/guidanceH.do?mode=download&articleNo=263163&attachNo=143312. Assessed 1 June 2020.
70. Noti JD, Lindsley WG, Blachere FM, Cao G, Kashon ML, Thewlis RE, McMillen CM, King WP, Szalajda JV, Beezhold DH. Detection of infectious influenza virus in cough aerosols generated in a simulated patient examination room. Clin Infect Dis 2012;54:1569-77.

71. Lofgren DJ. A must for NIOSH: certify fit performance of the half mask particulate respirator. J Occup Environ Hyg 2012;9:D191-5.

72. McMahon E, Wada K, Dufresne A. Implementing fit testing for N95 filtering facepiece respirators: practical information from a large cohort of hospital workers. Am J Infect Control 2008;36:298-300.

73. United States Department of Labor. Occupational Safety & Health Administration (OSHA). Assigned protection factors: for the revised respiratory protection standard. Available at: https://www.osha.gov/Publications/3352-APF-respirators.html. Accessed 1 June 2020.

74. Lee MC, Takaya S, Long R, Ioffe AM. Respirator-fit testing: does it ensure the protection of healthcare workers against respirable particles carrying pathogens?. Infect Control Hosp Epidemiol 2008;29:11491156.

75. Kim H, Lee J, Lee S, Oh J, Kang B, Lim TH, Kang H. Comparison of fit factors among healthcare providers working in the Emergency Department Center before and after training with three types of N95 and higher filter respirators. Medicine (Baltimore) 2019;98:e14250.

76. Institute of Medicine (IOM). The use and effectiveness of powered air purifying respirators in health care: workshop summary. Washington, DC: National Academies Press (US); 2015.

77. Gao S, McKay RT, Yermakov M, Kim J, Reponen T, He X, Kimura K, Grinshpun SA. Performance of an improperly sized and stretched-out loose-fitting powered air-purifying respirator: Manikin-based study. J Occup Environ Hyg 2016;13:169-76.

78. Roberts V. To PAPR or not to PAPR? Can J Respir Ther 2014;50:87-90.

79. Yan J, Grantham M, Pantelic I, Bueno de Mesquita PJ, Albert B, Liu F, Ehrman S, Milton DK; EMIT Consortium. Infectious virus in exhaled breath of symptomatic seasonal influenza cases from a college community. Proc Natl Acad Sci U S A 2018;115:1081-6.

80. Lindsley WG, Noti JD, Blachere FM, Thewlis RE, Martin SB, Othumpangat S, Noorbakhsh B, Goldsmith WT, Vishnu A, Palmer JE, Clark KE, Beezhold DH. Viable influenza A virus in airborne particles from human coughs. J Occup Environ Hyg 2015;12:107-13.

81. Liu L, Li Y, Nielsen PV, Wei J, Jensen RL. Short-range airborne transmission of expiratory droplets between two people. Indoor Air 2017;27:452-62.

82. Bischoff WE, Turner J, Russell G, Blevins M, Missael E, Stehle J. How well do N95 respirators protect healthcare providers against aerosolized influenza virus? Infect Control Hosp Epidemiol 2018;1-3. [Epub ahead of print].

83. Infectious Disease Society of America (IDSA). Infectious Diseases Society of America guidelines on infection prevention for health care personnel caring for patients with suspected or known COVID-19. Available at: https://www.idsociety.org/practice-guideline/covid-19-guideline-infection-prevention/. Assessed 1 June 2020.

84. Radonovich LJ Jr, Simberkoff MS, Bessesen MT, Brown AC, Cummings DAT, Gaydos CA, Lou JK, Krosche AE, Gibert CL, Gorse GJ, Nyquist AC, Reich NG, Rodriguez-Barradas MC, Price CS, Perl TM. ResPECT investigators. N95 Respirators vs medical masks for preventing influenza among health care personnel: a randomized clinical trial. JAMA 2019;322:824-33.

85. Long Y, Hu T, Liu L, Chen R, Guo Q, Yang L, Cheng Y, Huang J, Du L. Effectiveness of N95 respirators versus surgical masks against influenza: a systematic review and meta-analysis. J Evid Based Med 2020;13:93-101.

86. Bartoszko JJ, Farooqui MAM, Alhazzani W, Loeb M. Medical masks vs N95 respirators for preventing COVID-19 in healthcare workers: a systematic review and meta-analysis of randomized trials. Influenza Other Respi Viruses 2020;14:365-73.
87. Chu DK, Akl EA, Duda S, Solo K, Yaacoub S, Schünemann HJ. COVID-19 Systematic Urgent Review Group Effort (SURGE) study authors. Physical distancing, face masks, and eye protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19: a systematic review and meta-analysis. Lancet 2020. [Epub ahead of print].

88. American National Standard. Association for the Advancement of Medical Instrumentation (AAMI). ANSI/AAMI:PB70:2012 liquid barrier performance and classification of protective apparel and drapes intended for use in healthcare facilities. Available at: https://my.aami.org/aamiresources/previewfiles/pb70_1206_preview.pdf. Accessed 1 June 2020.

89. Government of Canada. Public Works and Government Services Canada (PWGSC). Specifications for COVID-19 Products. Available at: https://buyandsell.gc.ca/specifications-for-COVID-19-products#700. Accessed 1 June 2020.

90. World Health Organization (WHO). Ebola virus disease: operational support and logistics: disease commodity packages. Geneva: WHO; 2018.

91. Association for the Advancement of Medical Instrumentation (AAMI). AAMI TIR11:2005/(R)2015: Selection and use of protective apparel and surgical drapes in health care facilities. Arlington, VA: AAMI; 2005.

92. World Health Organization (WHO). Personal protective equipment for use in a filovirus disease outbreak: rapid advice guideline.2016;71. Available at: https://apps.who.int/iris/handle/10665/251426. Accessed 1 June 2020.

93. European Center Disease Control and Prevention (ECDC). Safe use of personal protective equipment in the treatment of infectious diseases of high consequence. Available at: https://www.ecdc.europa.eu/en/publications-data/safe-use-personal-protective-equipment-treatment-infectious-diseases-high. Accessed 1 June 2020.

94. Suen LKP, Guo YP, Tong DWK, Leung PHM, Lung D, Ng MSP, Lai TKH, Lo KYK, Au-Yeung CH, Yu W. Self-contamination during doffing of personal protective equipment by healthcare workers to prevent Ebola transmission. Antimicrob Resist Infect Control 2018;7:157.

95. Phan LT, Maita D, Mortiz DC, Weber R, Fritzzen-Pedicini C, Bleasdale SC, Jones RM; CDC Prevention Epicenters Program. Personal protective equipment doffing practices of healthcare workers. J Occup Environ Hyg 2019;16:575-81.

96. Hall S, Poller B, Bailey C, Gregory S, Clark R, Roberts P, Tunbridge A, Poran V, Evans C, Crook B. Use of ultraviolet-fluorescence-based simulation in evaluation of personal protective equipment worn for first assessment and care of a patient with suspected high-consequence infectious disease. J Hosp Infect 2018;99:218-28.

97. Wong TKS, Chung JYW, Li Y, Chan WF, Ching PT, Lam CHS, Chow CB, Seto WH. Effective personal protective clothing for health care workers attending patients with severe acute respiratory syndrome. Am J Infect Control 2004;32:90-6.