

COVID-19 AND RESPIRATORY PROTECTION FOR HEALTHCARE PROVIDERS

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Abstract

This article has investigated the considerations of healthcare facilities to utilize reusable respirators as an alternative to disposable respirators during the COVID-19 pandemic. The decision to choose specific equipment should be based on the protection factors and also on the overall analysis of given conditions. International scientific databases, such as Web of Science, PubMed and MedLine, were searched on May 5, 2020, with the following key words: COVID-19, respiratory protection, surgical masks, filtering facepiece respirators (FFRs) and disposable respirators. The differences between various respiratory protective equipment, i.e., surgical masks, respirators such as FFRs, elastomeric half-facepiece respirators, elastomeric full-facepiece respirators and powered air-purifying respirators (PAPRs), were compared. Reusable elastomeric respirators (RERs) may provide a better adaptation to the face and may be more stable when used by healthcare providers (HCPs). Protection factors were found to be higher in FFRs compared to surgical masks. While FFRs provide a one-tenth decrease in the inhaled aerosol concentration, PAPRs diminish the inhaled aerosol up to one-twenty-fifth. Even with some full-face PAPRs and helmets, the protection factor assigned by the Occupational Safety and Health Administration can reach a value up to 1000. For HCPs, the evidence shown in this article provides an additional support for the utilization of RERs. Such equipment might be less prone to leakages, can provide a better fit, and indicates a better stability compared to disposable FFRs (N95 and similar). By providing higher protection factors, reusable elastomeric respirators are recommended to be used by HCPs under controlled cleaning and disinfection protocols. *Int J Occup Med Environ Health.* 2021;34(2):307–18

Key words:

occupational health services, respiratory protective devices, pandemics, respirators, healthcare providers, occupational health of physicians

INTRODUCTION

Preliminary reports from Wuhan informed the World Health Organization (WHO) of the detection of a new type of coronavirus in several patients. This novel coronavirus was named as SARS-CoV-2, and on February 11, 2020, viral pneumonia caused by this virus was termed COVID-19 [1]. On March 11, 2020, after COVID-19 had spread worldwide, WHO declared the infection a pandemic.

When the novel SARS-CoV-2 was known to be transmitted possibly through inhalation, the respiratory protection of healthcare providers (HCPs) became of utmost importance. First, to better understand the available materials for the protection of respiratory airways, it is important that the relevant terminologies be defined so that differences between various types of equipment could be properly understood. Even though all pieces of respiratory protective equipment are often called masks, technically, there are differ-

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Figure 1. A surgical mask (SOLYCARE™, Turkey):
a) front view, b) lateral view



Figure 2. A FFP2 respirator (MFA™ Z-267, Turkey):
a) front view, b) lateral view

ences between a mask and a respirator. Surgical masks provide one-sided protection mainly to patients but not to HCPs. Surgical masks are made up of different pieces of fabric to cover the nose and mouth, and to provide the protection to patients from particulate aerosols and body fluids from HCPs. Surgical masks that have a loose fit provide one-sided protection and are not sufficient for protecting the wearer (Figure 1). Unfortunately, only few types of surgical masks are tested for quality whereas the rest do not have a calculated protection factor. Surgical masks are mostly described based on the number of layers they have, such as 2-layered or 3-layered surgical masks. Quality surgical masks mostly have a triple-layer design; the 2 outer layers are made of non-woven fabric, whereas the middle layer is made through melt-blowing. This middle melt-blown layer of the mask defines its filtering capability. However, surgical masks are not always evaluated based on that parameter.

Unlike surgical masks, filtering facepiece respirators (FFRs) are designed to protect the wearer. In hospitals, the use of FFRs protects HCPs. Additionally, FFRs provide

a better seal and fit than surgical masks; and tight-fitting facepieces generally have a higher protection factor. In general, FFRs are classified into 2 major types: valved and non-valved. Non-valved FFRs provide a sufficient respiratory protection to both HCPs and patients. In both types of FFRs, the air that passes through the respirator is filtered in both directions: inwards and outwards (Figure 2). These respirators achieve a good seal when properly worn. Moreover, the safety of these respirators is based on the standard security rating. They are also available as disposable respirators or reusable elastomeric respirators (RERs).

The Center for Disease Control and Prevention (CDC) has published a guidance against COVID-19 and advised the use of N95 respirators as standard protective equipment. This standard suggests that an N95 or better respirator, such as N99 or N100, is acceptable for the protection against the COVID-19 pandemic. The safety standard of the N95 respirator, which is a disposable respirator, is managed by the National Institute for Occupational Safety and Health (NIOSH) in the USA.

In Europe, different standard coding is used for filtering facepieces (FFPs) and particle filters. The European EN 149:2001+A1:2009 standard certifies FFP masks with increasing levels of protection scores marked as 1, 2, or 3; these scores correspond to the respirators labeled FFP1, FFP2, or FFP3. The European EN 149:2001+A1:2009 standard also specifies the particle protection of respiratory protective equipment. The other EN 143 standard covers particle filters and classifies them based on their P1/P2/P3 ratings. These 2 standards are both controlled and maintained by the European Committee for Standardization.

China has similar standards for FFP coding as the USA, with the Chinese KN95 standard being equivalent to the U.S. N95 standard. These standards are described by the Standardization Administration of China created on March 27, 2006, and the GB 2626-2006 standard. The GB 2626-2006 standard explains the technical requirements, testing methods, and the identification of particle respirators. These Chinese standards are employed against all types of particles for non-powered air-purifying respiratory protective equipment. In theory, the U.S. N95, European FFP2, and Chinese KN95 respirators have equivalent specifications. However, as the materials used in manufacturing and testing protocols differ in various countries, which makes standardization complicated, there is no certainty as to whether all the respirators provide equivalent protection at certain protection levels established in each country.

Reusable elastomeric respirators are preferred mostly by workforces in the industry, military, construction, and painting professions for respiratory protection. These respirators have a good fit and seal, which provides sufficient protection. These respirators are manufactured from flexible materials which are perfect for providing a good seal; if regularly maintained, they can be used for long periods, i.e., years [2].

For long-term use, the equipment must be stored under conditions as specified by the manufacturer, any deformed

parts must be replaced with original spare parts, and care has to be provided for cleaning and disinfection. While the whole body of RERs can last for many years, the removable filters or cartridges must be replaced regularly to ensure respiratory protection. The protective performance of RERs is highly affected by its capacity to provide a proper face seal; variations in its protective performance have been attributed to an insufficient seal [3]. Since the face seal is a highly important factor in the performance of respirators, the Occupational Safety and Health Administration (OSHA) in the USA requires fit testing of respirators prior to their extended use [4].

Air-purifying respirators which have air pressure sensors and control airflow every second are called powered air-purifying respirators (PAPRs). With these sensors, the air level inside the respirator is maintained at a pre-assigned value during use. With a powered motor, air passes from the filter or cartridges and stays inside the respirator. The airflow inside PAPRs provides efficient protection. The assigned protection factor (APF) and the face seal provided by PAPRs are higher and better, respectively, than those of RERs and FFRs. During the COVID-19 pandemic, HCPs work in environments with aerosols that may contain SARS-CoV-2 and, thus, PAPRs have been proposed to be used as respiratory protection equipment. There are different types of PAPRs, such as half-facepiece, full-facepiece, hood, or helmet. These respirators can achieve a rating of 1000 APF in testing, which indicates better effectiveness than that of FFRs.

In Wuhan in December 2019, bronchial samples were analyzed and SARS-CoV-2-infected cultures were examined under light microscopy, and the size of the virus was found to range 0.06–0.14 μm [5]. While COVID-19 has come to affect all continents in the world, the protection efficiency of various respirators against SARS-CoV-2 and biological agents is a question to be answered by scientists. The most important question that needs to be addressed is whether respirators can filter small particles such as spores, bac-

Table 1. Classification of various microorganisms based on their most penetrating particle size (MPPS) [5–11,13–15]

Physical size	Microorganism	Disease
<0.3 μm MPPS		
0.04 μm	<i>Hepatitis B Virus (HBV)</i>	viral hepatitis
0.07–0.09 μm	<i>Adenoviridae</i>	respiratory disease and multi-organ disease
0.08–0.012 μm	<i>Bunyaviridae</i>	hantavirus
0.08–0.012 μm	<i>Orthomyxoviridae</i>	flu pandemic and influenza
0.08 μm	<i>Filoviridae</i>	Ebola
0.12 μm	<i>Coronaviridae</i>	SARS-CoV-2
0.14–0.26 μm	<i>Variola vera</i>	red plague
>0.3 μm MPPS		
1.0–1.5 μm	<i>Bacillus anthracis</i> spore	anthrax
1.0–5.0 μm	<i>Mycobacterium tuberculosis</i>	tuberculosis
3.0 μm	<i>Bacillus</i> species	bloodstream infection
13.3–15.7 μm	<i>Staphylococcus aureus</i>	pneumonia, meningitis

teria, or viruses [6]. In Table 1, the sizes of some microorganisms are provided [5–11,13–15].

METHODS

Literature search for the journals included in the international scientific databases, such as Web of Science, PubMed and MedLine, were searched on May 5, 2020, with the following key words: COVID-19, respiratory protection, surgical masks, FFRs and disposable respirators. The differences between various respiratory protective equipment, i.e., surgical masks, respirators such as FFRs, elastomeric half-facepiece respirators, elastomeric full-facepiece respirators and PAPRs, were compared. While using the databases, an advanced option with “or” and “and” choices was used. The shortlisted articles were evaluated and selected in terms of relevance to this study design, with the impact of respiratory protection with surgical masks and FFRs.

Particles such as body fluids or dust may also be carriers of particles. For example, the particles produced when coughing or speaking may quickly form droplet nuclei, which were previously reported to be around 20 μm [7]. In an-

other report on the influenza virus, samples were obtained from expired air [8]. Another study on the size of *Mycobacterium tuberculosis* reported that the size of the droplet nuclei for this bacterium is approximately 1–5 μm [8,9]. Hospital room air containing the particles spread from patients infected with influenza was evaluated, and the size of the virus ranged 1–4 μm [10]. A fiber of 1–100 μm forms a diagonal stripe, creating layers of the filter structure in which air passes through, and the breathing ability of the respirators is calculated according to the inter-fiber spaces [11]. While air passes through these filters, particles can be trapped in the filters or pass through due to forces such as gravity, impaction, inertial impaction, spread, Coulomb interaction, diffusion, or interception [11].

Airborne particles of >100 μm can be filtered with respect to their velocity and affected by the gravity settlement, whereas many of the particles in the respiratory tract are very small particles that are not affected by gravity. Particles of >0.6 μm in diameter were mostly filtered by interception or inertial impaction [12]. When a particle cannot pass through fibers because of its inertia, impaction to the fiber occurs. Interception occurs when airborne par-

ticles are captured by the fibers [12]. For airborne particles of $\leq 0.1 \mu\text{m}$, diffusion was reported, as air molecules collide with particles and aerodynamics forces them to be filtered by the fibers due to their random movements [12]. As air passes through the filters, the particles are captured by various mechanisms. It has been found that the biggest challenge is not the interception of particles of extremely small sizes, but the interception of the particles sized approximately $0.05\text{--}0.5 \mu\text{m}$ [11]. The latter are not large enough to be intercepted by diffusion, and not small enough to be intercepted by inertial impaction or impaction [11]. Consequently, respirators are measured according to their efficiency in intercepting particles of $\geq 0.3 \mu\text{m}$, which is also defined as the most penetrating particle size (MPPS) [13].

There is a phenomenon called Brownian motion (BM), in which particles of $< 0.3 \mu\text{m}$ are intercepted easily as they do not travel in the air in a defined direction due to their relatively lower mass than that of air [14]. When these particles collide in the air with O_2 or N_2 , they change direction in an uncontrolled pattern and are easily intercepted by fibers [15]. Based on this research, not only the large particles were easy to filter but also the smallest size particles due to BM [15]. Table 1 classifies various microorganisms according to MPPS.

With BM in mind, one can assume that the respirators tested to the $0.3\text{-}\mu\text{m}$ particle size can intercept SARS-CoV-2, which is around $0.12 \mu\text{m}$ [5], to the efficiency level assigned by the authorities. This is due to the facts that are known from previous published studies. The research conducted during the ongoing pandemic will deliver information about the protection level provided by respirators against SARS-CoV-2. Until then, the protection levels are assumed based on the previous knowledge according to publications and international standards. For example, the interception of particles of $0.3 \mu\text{m}$ with an FFP2 respirator, i.e., the worse-case scenario, would be 94%, whereas 99.7% of such particles would be filtered with an FFP3 respirator. Filtration efficiency requirements and stan-

dards with APFs or nominal protection factors (NPFs) are compared in Table 2, including the efficiency requirements for various countries [2–4,13].

There are 2 types of FFRs depending on whether they have or do not a valve. Air inhalation is the same in both types of these respirators, whereas exhalation is easier in those with a valve (Figure 3). Valved FFRs are more appropriate for use in industrial plants as there is no filtration in exhalation and the protection is required only for the users. During the COVID-19 pandemic, the use of valved FFRs with a one-sided filtering mechanism might put others that the wearer interacts with at risk of infection. When valved FFRs are needed to create double-sided protection, a piece of cloth or a surgical mask can be additionally worn for partially filtering the air exhalation (Figure 4).

Cartridges are included in RERs, and filtering mechanisms occur in these removable cartridges. There are different models available for RERs with 1 or 2 cartridges (Figure 5), and these can be half- or full-facepiece respirators (Figure 6). The number of cartridges in use is more of a user's choice for the design; however, the filtering capacity is also important, and the particle filters which can be used in hospitals are labeled with letter "P" in relation to relative filtration efficiency standards (Table 2). This symbol stands for particulate filtering and numbers 1, 2, and 3 are the efficiency levels; more specifically, P1 corresponds to FFP1, P2 corresponds to FFP2, and P3 corresponds to FFP3.

The protection factor is defined as the protection level provided by a certain type of the respirator when worn according to the manufacturer's recommendations; a proper fit must be achieved for leakage control. The protection factor indicates the protection provided by a respirator compared to a situation when nothing is worn. The NPF corresponds to the maximum percentage of the total inward leakage (TIL) permitted by European standards (EN) for a given class of respirators. As NPFs were developed through laboratory tests by trained individuals, they

Table 2. Filtration efficiency requirements and standards with assigned or nominal protection factors for respiratory protective equipment [2–4,13,25,26,28,29,32]

Equipment	Origin	Standard	Filter classification	Efficiency	APFs*/NPFs*
FFR	USA	NIOSH 42/CFR 84	N95	≥95%	4 APFs
			N99	≥99%	10 APFs
			N100	≥99.97%	20 APFs
	Europe	EN 149:2001	FFP1	≥80%	4 NPFs
			FFP2	≥94%	12 NPFs
			FFP3	≥99%	50 NPFs
	China	GB 2626-2006	KN/KP90	≥90%	n.a.
			KN/KP95	≥95%	n.a.
			KN/KP100	≥99.97%	n.a.
Reusable elastomeric half-facepiece respirator	Europe	EN 143:2000/ EN 140:1999/ EN 136:1998	P1	≥80%	4 NPFs
			P2	≥94%	12 NPFs
			P3	≥99.95%	48 NPFs
Reusable elastomeric full-facepiece respirator	Europe	EN 143:2000/ EN 140:1999/ EN 136:1998	P1	≥80%	5 NPFs
			P2	≥94%	16 NPFs
			P3	≥99.95%	1000 NPFs
PAPR with a hood or a helmet	Europe	EN 12941 (TH1: inward leakage max 10%; TH2: inward leakage max 2%; TH3: inward leakage max 0.2%) HEPA	TH1	≥99.97%	10 NPFs
			TH2	≥99.97%	50 NPFs
			TH3	≥99.97%	500 NPFs
PAPR with a tight-fitting mask	Europe	EN 12942, HEPA	TM1	≥99.97%	20 NPFs
			TM2	≥99.97%	200 NPFs
			TM3	≥99.97%	2000 NPFs

APFs – assigned protection factors; FFR – filtering facepiece respirator; HEPA – high-efficiency particulate air; NPFs – nominal protection factors; PAPR – powered air-purifying respirator.

n.a. – not available.

* Europe uses NPFs, while USA uses APFs.

might not represent the true protection factor that one must achieve in a given workplace; these existing values are used more as a reference. In contrast, APFs are realistic factor values that translate to a situation when respirators are properly used. The APF values are more realistic than the NPF values as they were obtained through simulated workplace testing by appointed groups at national levels; however, the APF values may vary greatly between countries. These values should be noted (or are required to be used) when selecting respirators (Table 2).

Finally, PAPRs are slightly different from the previously analyzed respirators in this article. These respirators have a fan assistance that regulates air pressure inside the respirator and provides a positive air pressure. As PAPRs offer comfortable respiratory protection and integrated protection against multiple hazards, they help in ensuring respiratory, head, face, eye, and hearing protection. Some all-in-one kits designed for HCPs have maintenance-free disposable head covers designed to help protect HCPs from airborne particles without compromising comfort or flexibility.



Figure 3. A valved FFP2 respirator (3M™ 9926, USA): a) front view, b) lateral view



Figure 4. A valved filtering facepiece respirator (3M™ 9926, USA) + a surgical mask FFP2 (SOLYCARE™, Turkey) : a) front view, b) lateral view

RESULTS

Quality surgical masks mostly have a triple-layer design; the 2 outer layers are made of non-woven fabric and the middle layer is made through melt-blowing. This melt-blown layer defines the filtering capability of the mask and

is mainly made of plastic turned into a structure with minor filaments [16]. Additional features, such as an electrostatic field, can be incorporated during the manufacturing phase of surgical masks [16]. It has been reported that surgical masks with a melt-blown layer alone have a lower filtration



Figure 5. A reusable elastomeric half-facepiece respirator P3 Filters 6035 (3M™ 7502, USA): a) front view, b) lateral view



Figure 6. A reusable elastomeric full-facepiece respirator P3 Filters 6035 (3M™ 6800, USA): a) front view, b) lateral view

efficiency than those with electrostatic field; these masks are also reported to be stronger [16].

It is not logical to expect that all surgical masks are of the same filtering quality, as surgical masks are not classified by international standards as respirators. There are testing methods that are described by the American Society of Testing and Materials (ASTM) for analyzing surgical masks. According to ASTM, surgical masks are listed in 3 levels: 1 indicates the minimum and 3 indicates the maximum level of barrier protection. However, regardless of the barrier level specified, none of the surgical masks protects HCPs from SARS-CoV-2. Surgical masks are mainly used for protecting patients from HCPs and they provide no respiratory protection (Figure 1).

Currently, the COVID-19 pandemic is ongoing and there is no particular research comparing the filtering capacity of surgical masks and respirators. However, research data can be considered to provide guidance in protecting people against SARS-CoV-2, which is similar in size to the influenza virus; both viruses are transmitted in similar ways and cause infections in the respiratory system [17].

Radonovich et al. [18] conducted a randomized comparison of the effectiveness of surgical masks and respirators. In hospitals at 7 different locations in the USA, during the 12-week period of influenza and viral infections, the participants were grouped into the N95 group, which consisted of those who wore respirators, and the medical mask group consisting of those who wore surgical masks. From the 2862 participants in total, 2371 were reported to have completed the study [18]. Influenza infections were reported in 207 members of the N95 group and in 193 members of the medical mask group. Acute respiratory disease was reported in 1556 and 1711 participants of the N95 group and the medical mask group, respectively. Respiratory infections were reported in 679 and 745 participants of the N95 group and the medical mask group, respectively. Other respiratory disease infections occurred in different participants in each group, and all study data

were analyzed. Radonovich et al. [18] concluded that among the HCPs who wore N95 respirators and surgical masks, no significant difference was implied.

Another study conducted by Loeb et al. [19] analyzed the protection provided by surgical masks compared to N96 respirators utilized by HCPs during the influenza outbreak. In September–December 2008 in Ontario, Canada, 225 nurses were advised to use surgical masks, whereas other 211 were requested to use N95 respirators. During the assigned period, 50 nurses in the surgical mask group and 48 nurses in the N95 respirator group were infected with influenza. The results of the study by Loeb et al. [19] also did not indicate a significant difference in the occurrence of influenza infections depending on whether the nurses used surgical masks or N95 respirators.

In the 2006–2007 winter season, a randomized comparative trial was conducted by MacIntyre et al. [20] to compare whether the use of masks by the participants prevented influenza. In this study, 286 participants were included in a comparative trial, and it was reported that the use of masks decreased the infection risk. The authors concluded that the use of surgical masks could have decreased the transmission of the disease and would be greater during a pandemic.

Lai et al. [21] mentioned the control of spread of 2019-nCoV and strongly described COVID-19 as a global threat, especially to HCPs. Until an effective evidence-based treatment modality or vaccination is found, all preventive protection measures are persistently recommended.

MacIntyre and Chughtai [22] recently reviewed 19 articles on the utilization of respiratory protective equipment. Eight of these articles were in community settings, 6 were in hospital settings, and 5 were taken as source control. The authors reported that if HCPs had worn respirators uninterruptedly during their work shifts, the respirators could have provided effective protection. MacIntyre and Chughtai [22] further reported that surgical masks were not protective and that textile-fabricated cloth masks were

even more inadequate, but they simultaneously stated that surgical masks could be utilized beneficially for eliminating the transmission in the community as a preventive measure of cross-infection. The review article clearly supports the continued use of respiratory protective equipment and emphasizes that HCPs could be protected by respirators from aerosols that may contain SARS-CoV-2.

During the COVID-19 pandemic, with the increasing demand and shortage of protective respiratory materials, hospitals are considering the use of RER devices as an alternative to FFP2, or equivalent disposable respirators.

The protection factor studies described by Liverman et al. [2] demonstrated that RERs, with their good fit and seal characteristics, provide a superior and more efficient protection than disposable FFRs [23–26]. It was reported that the protection provided by RERs was 60% higher than that of disposable FFRs in healthcare settings [2,26]. In addition, P100 disposable FFPs and P3 (EU)/P100 (USA) RERs were tested against nanoparticles of the same sizes for performance in agricultural settings, with RERs being reported to provide a higher protection factor than disposable FFRs [25]. Moreover, CDC has recommended reusable FFRs for respiratory protection of HCPs, and advised on the utilization of products approved by the Food and Drug Administration (FDA) and NIOSH [27]. With a good face seal, half- or full-facepiece RERs were expected to diminish the virus concentration to one-tenth of the original concentration.

In comparison to FFRs providing a 10-fold decrease in inhaled aerosol concentration, PAPRs diminish the inhaled aerosol by up to one-twenty-fifth. Even with some full-facepiece PAPRs and helmets, the APF assigned by OSHA can be up to 1000. Evidence for such a high value has to be demonstrated in testing the protection devices through the use of the manufacturer-recommended fit and seal; loose-fitting helmets and PAPRs have been reported to have the protection factor of 25. When used properly, PAPRs have higher APFs than both disposable respirators and half-facepiece RERs.

Notably, PAPRs are named according to their fit, such as loose- or tight-fitting, or according to the area covered, such as full-facepiece or half-facepiece. These respirators have different types of fans or blowers with adjustable airflow ranges, and they mainly have high-efficiency particulate air (HEPA) filters with 99.97% efficiency against MPPS of 0.3 μm . There is a wide range of products and filters, which makes PAPRs a suitable option for use in healthcare settings. Among all respirators, HEPA filters with tight-fitting full-facepiece PAPRs provide the highest efficiency of filtering (class TM3).

Even though there are few reports about the utilization of RERs in hospital conditions, scientific evidence shows a probability of decreased leakage [28], face-adjusting functionality, fit-securing head straps, and a long-lasting elastomeric adaptation to the face. Therefore, it has been suggested that these respirators could be used by HCPs [23]. However, Jannsen et al. [29] emphasized the importance of additional data requirements to evaluate the correlation between leakage, fit-to-face, and sustainability throughout use; these factors were also suggested to be compared with those of disposable FFPs.

Along with the fact that PAPRs with loose-fitting helmets or hood design are more easily worn, they do not require a thorough fit test for leakage control, and can be worn even with facial hair. These characteristics of PAPRs have been described as advantages over RERs. It has also been reported that PAPRs have loose-fitting headgears and allow the face of HCPs to be seen by patients, which enables better communication. Furthermore, parts of PAPRs can be cleaned or changed in the case of a malfunction.

The major limiting factor for the utilization of RERs by healthcare institutions is related to concerns about the cleaning and disinfection of such equipment. In a laboratory setting, the reprocessing protocols were defined by Lawrence et al. [30]. They evaluated the effectiveness of this equipment for an influenza pandemic. More specifically, 5 half-facepiece RERs and 3 PAPRs units were tested.

Forty-one surfaces were contaminated with the influenza virus, following which they were cleaned and disinfected. Lawrence et al. [30] concluded that the methods they explained could be effective in cleaning and disinfecting influenza viruses. Moreover, these data might overcome some concerns regarding the effectiveness of the cleaning and disinfection of reusable respiratory devices such as half- or full-facepiece elastomeric respirators and PAPRs.

Disinfection methods have also been studied, and cleaning protocols have been described for reusable respiratory devices that are intended for use during a pandemic. In the maintenance of PAPRs, chemical substances could damage respirators, so substances such as quaternary amines in oilfield parlance should not be used. Some disinfectants have also been reported as unsuitable and ineffective for disinfection procedures. There are currently no cleaning protocols or SARS-CoV-2 disinfection procedures established for reusable respiratory devices.

Even though there are concerns about the cleaning and disinfection methods of RRs, these devices provide higher protection factors than disposable filtering respirators, thereby justifying the need for further evaluation or recommendations of reusable respiratory protective equipment to HCPs. In a recent publication by Lee et al. [31], protection against particles of 0.093 and 1.61 μm , which also covers the size of SARS-CoV-2, was tested for various types of disposable facepiece respirators. Among the tested respirators, nearly 11% of FFP2 and 28% of FFP3 respirators showed protection factors below the APF described by the British standard. The protection factors were found to be 11.5–15.9 times higher in FFP respirators than that in surgical masks. Furthermore, a strong correlation between the fit-to-face characteristic and the protection factor was determined [31].

CONCLUSIONS

This review has investigated considerations in healthcare facilities such that reusable respirators are used as an alternative to disposable respirators in the case of market

shortages during the COVID-19 pandemic, and the issues to consider in choosing specific reusable personal respiratory protective equipment. The decision to choose specific equipment should be based not only on the protection factors but also on the overall analysis of specific conditions. The users' training levels, workplace conditions, and work intensity, along with the breathing rate, the amount of body movement, the maintenance of equipment, the hazards posed by substances, viruses or bacteria, and their concentration levels should all be considered and preferably analyzed before selecting respiratory protection equipment. Considering the COVID-19 pandemic conditions, the respiratory protective equipment with higher protection factors have to be provided for HCPs, especially in emergency care units, intensive care units, family primary care units and COVID-19 patient services.

For HCPs, the evidence shown in this article provides an additional support for the utilization of RERs. Such equipment might be less prone to leakages, can provide a better fit, and indicates a better stability compared to disposable FFRs (N95 and similar). By providing higher protection factors, RERs are recommended to be used by HCPs under controlled cleaning and disinfection protocols.

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