

## MINI-REVIEW

# How effective is a mask in preventing COVID-19 infection?

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**Abstract**

The main clinical characteristics of COVID-19 are respiratory symptoms that can lead to serious cardiovascular damages and severe worsening of other medical conditions. One of the major strategies in preparedness and response to COVID 19 is effective utilization of personal protective equipment (PPE) among which the masks of different kinds are on the top of the list especially for activities in the public places. However, the underlying mechanisms of masks in preventing virus transmission have not been well identified and the current experimental data still show inconsistent outcomes that may mislead the public. For instance, the early understanding of the mask functions was limited especially in the escalating phase of the COVID 19 pandemic, resulting in quite controversial remarks on masks. Although extensive studies in mask functions have been carried out ever since the COVID-19 outbreaks, most of the investigations appear to have focused on exhalation isolation of individuals who may have been infected with the disease. Less emphasis was laid on inhalation protection from virus transmission, an important aspect that undergirds the public health policies and protective strategies. This review provides the most up-to-date information on the transmission modes of COVID-19 virus in terms of droplets and aerosols. The roles of masks in disease prevention and transmission reduction are evaluated on various types, structures and functions. More important, both aspects of exhalation isolation and inhalation protection are discussed based on virus transmission modes and the effectiveness of different types of masks under varied environmental conditions.

**KEYWORDS**

COVID-19, epidemic prevention, mask

## 1 | INTRODUCTION

Since the outbreak of the coronavirus disease 2019 (COVID-19), the world has seen waves of coronavirus that have devastated many regions and countries. However, there are still many unknowns to be yet discovered about the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) that cause COVID-19. A year later since the first COVID-19 case, the evolution of the outbreak has remained in the escalation phase in the United States according to the latest (CDC, 2020; China's Response to the Pneumonia Outbreak in Wuhan Has Been Far Better Than Its Reaction to SARS.; Coronavirus

COVID-19 (2019-nCoV); Fortune, 2020; Time, 2020). The reported numbers of people who have been infected by COVID-19 are not to be entirely predictable as the outbreak is in a dynamic mode, making the assessment of the pandemic extremely difficult. Nonetheless, current medical science research has revealed some basic characteristics of the coronavirus based on which precautionary measures have been established. COVID-19 is known to be transmitted through invisible respiratory droplets that can be carried in the air for a prolong period of time. These virus-carrying droplets, originated from coughs and sneezes of an infected person, can land on any surfaces of humans and objects where the infectious disease

is further spread contagiously and rapidly (Service R, 2020). More dangerously, an infected person may carry and transmit COVID-19 without showing any symptoms for 14 days, posing latent threat to people in close contact, especially in public places such as on trains and airplane (Science Alert, 2020). There have been major methods, recommended by CDC and The Environmental Protection Agency via standard disinfectants in the first quarter of 2020 (CDC, 2020; US EPA, 2020). These include hand sanitizer, alcohol and a diluted solution of sodium hypochlorite, or household bleach. Although it has been recommended that the coronavirus can be destroyed by most disinfectants, no systematic studies that have yet shown their precise effectiveness on killing or deactivating the COVID-19 coronavirus (NBC news, 2020).

As of July 19, 2020, the World Health Organization (WHO) confirmed 14,043,176 COVID-19 cases and 597,583 reported deaths, indicating imminent danger to mankind. COVID-19 is well-known for its high transmission and mortality rate of the coronavirus, making it one of the most dangerous crisis that human beings have encountered since the Second World War. Without the specific therapeutics and vaccines, the key to stop the spreading of COVID-19 has to be dependent on preventative precautions by all means possible among which social distancing and quarantine have not only been recommended but also mandated by various state and federal regulations especially for those who have been infected (CDC, 2019, 2020; Parmet & Sinha, 2020). However, the asymptomatic carriers and misdiagnosis in nucleic acid tests make it more difficult to isolate the patients, therefore increasing the risks of virus spreading (Bai et al., 2020; Qu et al., 2020). Thus, the physical protection for individuals is necessary to curb virus transmission, and one common and widely used method is wearing of masks.

In order to control the development of the epidemic, the US Centers for Disease Control and Prevention (CDC) recommended the public to wear cloth masks on 3 April 2020 (Eikenberry et al., 2020), while the effectiveness of a mask was initially not clearly described and confirmed especially during the escalation phase in the first quarter of 2020. Some of the comments by medical researchers even posted quite different and controversial opinions on the issues of mask wearing that resulted in some confusions in the public (Cheng et al., 2020; Marasinghe, 2020; Zhou et al., 2020). Mask wearing policies and regulations have also varied from different countries and stages since the pandemic outbreak. Despite the different views of the masks, there has recently been a dramatic increase of public awareness and recognition of their significant roles in control of the pandemic (Goldberg et al., 2020).

One major disagreement lied on the necessary requirement of mask wearing in the public places especially for those who are not infected with COVID-19. For example, Hong Kong recommended mask wearing for all in order to prevent respiratory viruses, while Germany claimed no evidences that the masks could significantly reduce infection risks for healthy people (Feng et al., 2020). Furthermore, there have been disputes on the effectiveness of different types of masks for public usage, such as N95 respirators, medical masks and home-made cloth masks (Feng et al., 2020; Loeb

et al., 2009). Discussions on COVID-19 related issues, particularly on mask mandate have been the major topics in the public life. So far, the research communities have not been able to provide conclusive and unified remarks on the effectiveness of the masks in fundamental mechanisms and specific functions, although face mask requirements have been recently issued by all states in the United States. It is, therefore, critical to provide first-hand information to the general public and healthcare organizations on the overall performances of common and typical masks in a straightforward and tutorial fashion.

Based on the current research data, we analysed the transmission patterns of COVID-19 pertaining to the effectiveness of the masks of various types in terms of the mask materials and structures. The effectiveness of a mask is explained from the perspectives of both exhalation isolation and inhalation protection. This review aims to provide the up-to-date scientific research outcomes on the typical masks that have provided one of the most effective and viable means in combating COVID-19.

## 2 | TRANSMISSION MODE OF COVID-19

COVID-19 virus is mainly detected in air which is responsible for spreading of the disease (Chia et al., 2020). According to the current research, one of the major routes of transmission of COVID-19 virus is primarily via droplets from speaking, coughing or sneezing (Burke et al., 2020; Chan et al., 2020; Howard et al., 2020; Huang et al., 2020; Li et al., 2020; Liu, Liao, et al., 2020; Mittal et al., 2020; WHO, 2020). While 95% of droplets is smaller than 100  $\mu\text{m}$ , the majority are in the range from 4–8  $\mu\text{m}$  (Morawska et al., 2009). When the size threshold reaches a minimum around 5–10  $\mu\text{m}$ , the droplets are usually denoted as the respiratory droplets (World Health Organization, 2020). Bahl et al. (2020) summarized recent studies on COVID-19 transmission and concluded that the droplets spreading distance is increasing with the decreasing droplets size. The droplets with sizes of 1 to 5 mm can generally spread in a distance over 1–2 m from the source of infection (Wang & Du, 2020). The research of Bourouiba et al. (2014) showed that droplets of 30  $\mu\text{m}$  can have a horizontal range up to 2.5 m away from the cougher due to cloud dynamics, while the smaller droplets may even reach 4–6 m. According to these studies, the range of respiratory droplets transmission appeared to be a major factor in virus transmission. Only with a proper protection of a mask in daily life can a social distancing of 1.8 m (or 6 feet) be reasonably assumed an effective protection (Setti et al., 2020).

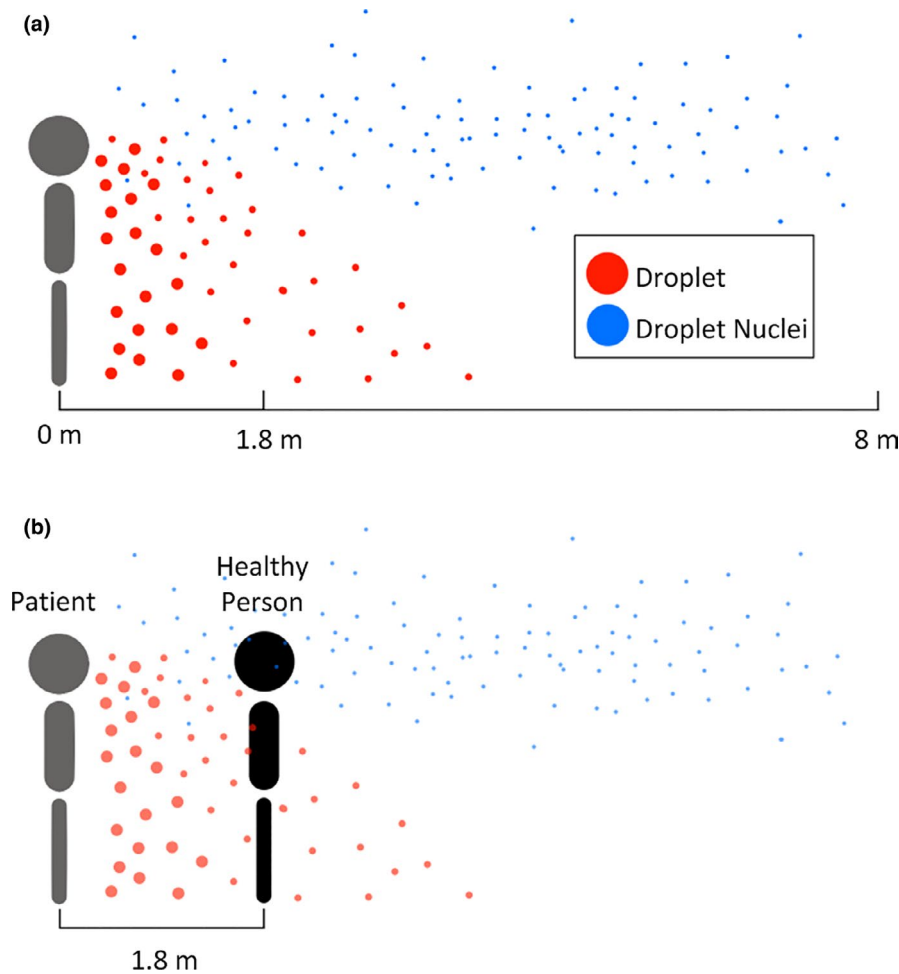
Wells reported that droplets with diameters greater than 100  $\mu\text{m}$  can settle to the ground in less than 1 s without significant evaporation while the droplets smaller than 100  $\mu\text{m}$  may evaporate quickly and dry into droplet nuclei within 6 s (Wells, 1934). The droplet nuclei, which are generally considered to be particles with diameters <5  $\mu\text{m}$ , can remain in the air for hours (Asadi et al., 2020). Larger droplets with virus content spread less significantly, but smaller droplets may propagate further distances (Morawska & Cao, 2020). Another research found that aerosols containing the COVID-19 virus can remain in the air for 3 h (Van Doremalen et al., 2020).

Those aerosols that can transit longer distances and stay stable in the air for long time are known to be responsible for the typical transmission mode: airborne transmission (Morawska & Cao, 2020; Van Doremalen et al., 2020). Through the terminal settling velocity of particles, the time required to fall 1 m under the action of gravity can be calculated (Tsuda et al., 2013). The particles of 100, 10, 1 and 0.1  $\mu\text{m}$  are settled to ground from 1 m, respectively, in 3.3 s, 5.6 min, 9.3 h and 39 days (Kohanski et al., 2020). The reduction of infectious aerosols can be achieved by increasing the ventilation rate of buildings and using efficient filtration (Kohanski et al., 2020). Hospital-based clinic rooms need at least 6 air changes per hour (ACH), and operating rooms require at least 15 ACH times (CDC, 2020).

When a person breathes, talks or coughs, droplets and droplet nuclei can fly as far as 8 m (26 feet) (Mover et al., 2020). Figure 1a is a schematic diagram showing the droplets and droplet nuclei propagating in the air. The spreading distance of droplet/droplet nuclei is seen to be greater than the social distancing of 1.8 m (6 feet), indicating the potential risks at the recommended range (Mover et al., 2020). This scenario is more clearly illustrated in Figure 1b; when a patient comes in close contact with another individual, even at the boundary of social distancing of 1.8 m (6 feet), there is still a high

risk of being infected by the patient's droplets that carry the virus. Environmental conditions such as wind and humidity can further worsen the risk factors via enhanced distributions of the droplets in the air.

Airborne transmission is possible under the condition of long exposure to high concentrations of aerosols in a relatively closed environment (Liu, Ning, et al., 2020). Except the aerosols, a recent review indicated that particulate matter (PM) air pollution was also responsible for long distance airborne transmission (Setti et al., 2020). Although no direct association was found between COVID-19 cases and  $\text{PM}_{10}$  concentration (Bontempi, 2020), evidence of virus spreading through the air showed the possibility of airborne transmission. An investigation conducted in two hospitals found the RNA of COVID-19 retrieved in air samples from isolation wards and toilet areas used by the patients (Liu, Ning, et al., 2020). Although the concentration of COVID-19 RNA was found quite low in the ventilated patient rooms, significant airborne presence of the virus was discovered in two public spaces with a high density of people (Liu, Ning, et al., 2020). In the Bergamo area (the epicentre of the Italian COVID-19 epidemic), air samples over a continuous 3-week period showed positive results in gene test of COVID-19 (Setti et al., 2020).



**FIGURE 1** a) Schematic diagram showing droplet and droplet nuclei propagating in the air; b) droplet and droplet nuclei propagating between a patient and a healthy person

These observations provided a base for precautionary measures especially for the healthcare workers who treated the COVID-19 patients (Mover et al., 2020).

### 3 | CATEGORIES OF MASKS

Masks are classified into three categories: namely, surgical masks, air filtering respirators and cloth masks with no testing standard. Surgical masks are made of non-woven fabrics with a multi-layered structure consisting of a leak proof layer, a high density filter layer, and a direct contact skin layer (Henneberry, 2020). Surgical masks fit loosely to the face with a flexible metal nose clip. Air filtering respirators are also made of multiple layers of non-woven fabric, often composed of polypropylene (Henneberry). Their geometric dimensions are generally fixed but with one more pre-filtration layer than the surgical masks. This additional layer is typically used for shaping, enabling a better fit to the face (Henneberry). Prolonged use of any face mask, including the N95 respirator can apply considerable facial stresses causing quite discomfort. For some persons with severe chronic lung disease, wearing a mask may make breathing more difficult, but not because of CO<sub>2</sub> retention. Moreover, the filtration layer has a higher density than the surgical masks, therefore more capable of blocking smaller particles (Henneberry).

N95 masks are one of the most common air filtering respirators which are currently in high demand during the COVID-19 pandemic. N95 is a test standard of the U.S. National Institute for Occupational Safety and Health (NIOSH) air filtration rating, which provides the classification of filtering respirators (CDC, 2020). According to the standards of NIOSH, filtering respirators can be classified as the N95, N99 and N100 masks, which can respectively block at least 95%, 99% and 99.97% of particles with median diameter of 0.3  $\mu\text{m}$  from entering (CDC, 2020). N95 respirator should be preprocessed in accordance with the requirements of the NIOSH 42 CFR 84 particulate respirator certification protocol (samples are taken out of their original packaging and placed in a preconditioning chamber at 85%  $\pm$ 5% relative humidity and 38°C  $\pm$  2.5°C for 25  $\pm$  1 h). Table 1 shows filter performances for different standards of air filtering respirators as compared to the U.S. NIOSH N95 (3M, 2020). Cloth masks are those without testing standard include cotton masks, self-made cloth masks and other substitutes. The quality of these masks varies depending on the materials, structures and methods of making.

### 4 | FUNCTION OF MASKS IN RESPIRATORY EPIDEMIC

The perspective of research on the effectiveness of masks can be divided in two different categories: 1. the source control and 2. the protection of the wearer (Chan & Yuen, 2020; Mittal et al., 2020).

TABLE 1 Different standard of air filtering respirators

Country	US	Europe	China	Australia, New Zealand	Korea	Japan
Certification /Class (Standard)	N95 (NIOSH-42CFR84)	FFP2 (EN 149-2001)	KN95 (GB2626-2006)	P2 (AS/NZ 1716:2012)	Korea 1 <sup>st</sup> Class (KMOEL-2017-64)	DS2 (Japan JMHLW-Notification 214, 2018)
Filter performance (must be $\geq$ X% efficient)	$\geq$ 95%	$\geq$ 94%	$\geq$ 95%	$\geq$ 94%	$\geq$ 94%	$\geq$ 95%

#### 4.1 | Source control (exhalation isolation)

Figure 2 schematically illustrates the function of a mask in reducing the respiratory products from spreading (Hui et al., 2012). As shown in this figure, airborne transmission is highly likely due to propagating droplets in the air as described above particularly those of smaller sizes including respiratory droplet nuclei and aerosols that are capable of travelling over the social distancing range over 1.8 m (Figure 2a). Wearing a mask, as depicted in Figure 2b, will effectively block the respiratory cloud, although the side leakage is possible. Some studies indicated that wearing a mask can reduce the generation of infectious aerosol during cough (Figure 2b; Jefferson et al., 2008; Johnson et al., 2009; Loeb et al., 2009). Among all types, N95 masks are more effective than surgical masks in preventing air leakage during cough, however, neither would entirely prevent the side leakage (Hui et al., 2012). Studies also showed that medical masks have potential advantages in clinical respiratory illness source control, but less significant in protection against influenza virus infection and laboratory-confirmed viral respiratory infections (MacIntyre et al., 2016). Surgical masks are similar to N95 masks in reducing the spread of respiratory diseases, but with a better comfort level compared to N95 (Jefferson et al., 2008; Loeb et al., 2009).

Without respiratory cloud, the transmission range of the leaked particles is largely reduced (Figure 2). Interestingly, the number of viruses carried by the small droplets was found to be less than that of the large droplets (Noti et al., 2012), indicating varied risks

of infection according to the distributions of small/large droplets. Wearing masks correctly can then significantly improve their effectiveness since complete seal of respiratory particles is unlikely due to side leakage of droplets with different sizes. Correctly wearing of the surgical masks was shown to be more effective than using the N95 masks even the latter has a better facial fit (Noti et al., 2012). Davies et al. (2013) recruited 21 healthy volunteers and collected air samples of each volunteer in three different conditions: 1. wearing a mask made of T-shirt, 2. wearing a surgical mask, and 3. wearing no mask. Although significant differences in filtration efficiencies were found between the T-shirt and the surgical masks, the former showed considerable reduction of respiratory droplet transmission, indicating its significance in a pandemic. Ho et al. (2020) carried out similar experiments on adult volunteers wearing medical masks or self-designed triple-layer cotton masks in two different surrounding environments: a regular bedroom and a car with air conditioning on (doors closed). They found both types of masks were capable of suppressing respiratory droplets to certain degrees.

#### 4.2 | Protection of the wearer (inhalation protection)

During the initial period of the COVID-19 outbreak in the first quarter of 2020, the public understandings on the key functions of the masks were quite limited without much of the first-hand

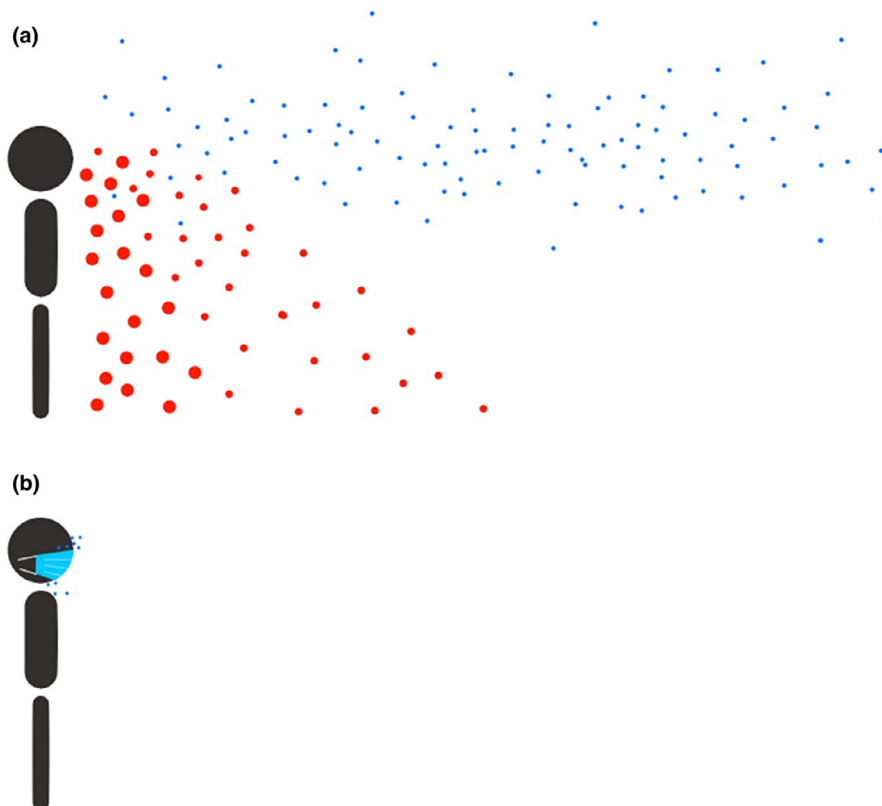


FIGURE 2 Differences of droplet and droplet nuclei transmission a) without and b) with mask

COVID-related experimental data at the time. Some media even suggested that it was not necessary to wear masks in public (Public Health Experts Keep Changing Their Guidance on Whether or Not to Wear Face Masks for Coronavirus; WHO, 2020). Both inconsistent explanations and the shortage of commercial masks may have contributed to such public opinion. Furthermore, in the first escalating phase of the pandemic, exhalation isolation was much more emphasized, and the masks were mainly recommended only for those of the COVID-19 patients. This public narrative, supported by some healthcare communities led to the believe that it is not necessary to wear masks in public for healthy people especially when there is a shortage of supplies. Only until recently, face mask requirements have been issued but policies still vary from state to state in the United States, and from country to country in the world.

Presently, research has just discovered that wearing masks is absolutely essential at all times, particularly when in direct contact with patients (who already wear surgical masks) (Sung et al., 2018). Recent data also show great significance of inhalation protection via masks. Figure 3 schematically illustrates the role of mask in inhalation protection. As shown in this figure, significant respiratory cloud with both droplets and droplet nuclei can propagate in the air with a high density especially in close contact with a patient. By wearing a mask, even a cloth one, the chance of getting infected for the healthy person is largely reduced in this high exposure risk environment (Figure 3). A face-to-face interview investigation was conducted with several medical staff on the effectiveness of wearing masks in a clinical setting. The outcome of the investigation indicated a more protective effect by the medical masks over those home-made cotton ones on respiratory tract infection (Yang et al., 2011).

A surgical mask is mainly intended for health professionals including physicians and nurses for protection during medical procedures. It is designed to prevent liquid droplets and aerosols from the wearer's mouth and nose. They are also designed to prevent cross-contamination between respiratory particles of a wearer and body fluid of patients during surgery (Henneberry, 2020). Although surgical masks are not designed to filter out viruses which are smaller

than bacteria, they can be as effective as respirators, such as N95 for preventing Influenza among health care personnel (Radonovich et al., 2019) and against respiratory droplets during the outbreak (Bartoszko et al., 2020).

Air filtering respirators such as N95 masks can filtrate contaminants, bacteria and other matters from reaching nose and mouth. A study based on MS2 Virus indicated that N95 masks have a much higher efficiency on virus penetration inhibition than surgical masks (Bałazy et al., 2006) These N95 s were tested for particle penetration of charge-neutralized sodium chloride aerosol spray, at a moderately high airflow rate of 85 L/min and a considerable breathing resistance. The mask was clogged up with aerosol particles to simulate a high level of exposure (Bałazy et al., 2006). The research found avian flu virus passing through the N95 mask, but its transmission did not necessarily imply direct infection because many other factors involved (Wiwanitkit, 2006). In addition, influenza is generally transmitted through small aerosol particles with a diameter of 1–10  $\mu\text{m}$ . It is possible that a single virus particle can be transmitted from person to person (Wiwanitkit, 2006).

The most predominant filtration mechanisms for a high efficiency fibrous filter in capturing particles are interception, inertial impaction and diffusion (TSI Incorporated, 2020). Interception occurs if a particle is captured by a fibre when it is in the vicinity. Inertial impaction effects are observed typically on some large particles when they are captured by fibres due to particle inertia in the direction from their original paths. Diffusion mechanism is mainly identified for small particles in Brownian motion with diameters below 0.1  $\mu\text{m}$ . These small particles tend to move randomly and collide with each other frequently (TSI Incorporated, 2020). Based on these mechanisms, particles near 0.3  $\mu\text{m}$  are more likely to pass through the filter than any other sizes (TSI Incorporated, 2020). Hence the filtration capacity of 0.3  $\mu\text{m}$  particles can be used to represent a standard for all particle sizes. With different filtration capacities, the air filtering respirators can prevent airborne transmission in a wide size range of droplets, especially in the indoor areas with a high population density, poor ventilation and hence a greater chance of virus exposure.

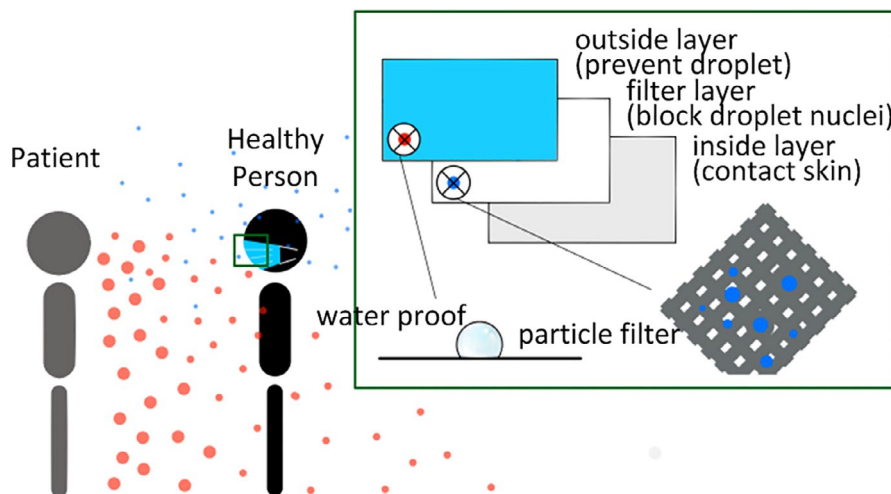


FIGURE 3 Protective mechanism of a mask when in close contact with a patient



It was found that some surgical masks may allow a considerable proportion of airborne virus to pass through the filter, resulting in insignificant protection against aerosolized infectious agents in the 10 to 80 nm range (Bałazy et al., 2006). Both surgical masks and N95 respirators can provide similar protection for the healthcare workers during non-aerosol generation care, but N95 is recommended for the high-risk environments (Bartoszko et al., 2020).

Due to limited access to surgical and N95 masks, self-made masks have become a popular means for self-protection especially in public places amid the current pandemic. Several studies on the characteristics of cloth masks are listed in (Table 2; Dato et al., 2006; Jung et al., 2014; Konda et al., 2020; Ma et al., 2020; Rengasamy et al., 2010). Some of the self-made masks were tested and found quite effective although to a lesser degree compared to the surgical and N95 masks (Mahase, 2020). Research has also been recently carried out on the common materials for making masks. Rengasamy et al. (2010) tested five major categories of fabric materials including sweatshirts, T-shirts, towels, scarves and cloth masks with polydisperse and monodisperse aerosols (20–1000 nm) at two different face velocities, and compared their penetration levels with those of the N95 respirator filter media, in order to evaluate the filtration performance of common fabric materials against nano-size particles including viruses. Konda et al. (2020) examined several common fabrics for the same purpose including cotton, silk, chiffon, flannel, various synthetics and their combinations. They determined the aerosol filtration efficiencies of different masks with cotton quilt or the cotton/chiffon hybrid sample, and found their filtration efficiencies even higher than those of N95 respirators or surgical masks for the particles smaller than 300 nm (Konda et al., 2020). Wang et al. compared surgical masks with those made of 17 different materials including some cloth and other fabrics (Wang et al., 2020). Davies et al. (2013) experimented on the filtration efficiencies and pressure drop of several common fabrics and surgical masks, and concluded that cotton T-shirts can be the most suitable household materials

for an improvised face mask. Zhao et al. (2020) found that the cloth masks may have comparable filtration efficiencies to medical masks.

These research results indicate plausible performances of the cloth masks made of common materials which may serve as effective alternatives in combating COVID-19. They are considerably effective and economic in minimizing the chance of infection especially when the medical masks are not readily available to the majority of people. (Bałazy et al., 2006; Konda et al., 2020; MacIntyre et al., 2016; TSI Incorporated, 2020).

### 4.3 | Cases studies on protection effective of masks

Mask effectiveness has been demonstrated in prevention of influenza and some other infectious diseases. Van der Sande et al. (2008) showed that the use of any type of ordinary mask may reduce the risk of exposure to viruses and infections. Some observational results confirmed that frequently using masks in a community can prevent spread of infection from sick and infectious people (Jensen et al., 2005; Rockwood & O'Donoghue, 1960; Srinivasan et al., 2004; Weaver, 1919). As a non-pharmaceutical intervention to control virus transmission during the influenza pandemic, persistent use of masks significantly reduced the risk of influenza-like-illness-associated infection (Cowling et al., 2008; MacIntyre et al., 2009). Masks were shown to have protective efficacies in excess of 80% against clinical influenza-like-illness (Macintyre et al., 2008). Sung et al. found that requiring people who have direct contact with patients to wear surgical masks can considerably reduce respiratory virus infection (Sung et al., 2018). A face-to-face interview suggested greater protective effect of medical masks than the cotton masks (Yang et al., 2011). Masks and hand hygiene may reduce respiratory diseases in shared living environments and mitigate the impact of pandemic influenza A (H1N1) (Aiello et al., 2010; Jefferson et al., 2008).

TABLE 2 Summary of characteristic studies on cloth masks

Author, year	Materials	Method	Results
Dato et al. (2006)	8-layer cotton T-shirt mask	Measuring aerosol concentration outside and inside the mask.	67% effective prevention of aerosols considering N95 to be 100%.
Rengasamy et al. (2010)	Five categories of fabric materials	Testing the filtration performance for polydisperse and monodisperse aerosols.	Significantly higher aerosol penetration level than N95 respirator.
Jung et al. (2014)	Medical masks, general masks and handkerchiefs	Observing a wide variation of penetration and pressure drops	No significant difference among these masks with little protection against aerosols.
Ma et al. (2020)	N95 masks, medical masks and home-made masks (four-layer kitchen paper and one-layer cloth)	Evaluating the efficacy of masks and instant hand wiping using the avian influenza virus.	N95 masks, medical masks and home-made masks can block 99.98%, 97.14% and 95.15% of virus in aerosols.
Konda et al. (2020)	Several common fabrics and their combinations	Using aerosol to determine filter efficiencies	The efficiencies of cloth masks with multiple layers are similar to those of surgical masks.

Wearing masks can also reduce the risk of avian influenza infection (Wiwanitkit, 2006). Some studies explored the impact of mask use during influenza by establishing a population transmission model from an epidemiological perspective. The results showed possibility of delaying the pandemic by wearing masks nationwide (Brienen et al., 2010; Chan & Yuen, 2020).

Amid the COVID-19 pandemic, a retrospective study of 335 people from 124 families in Beijing found that the use of masks by primary cases and family contacts could effectively reduce the transmission of COVID-19 (Wang et al., 2020). Chan et al. established a golden Syrian hamster COVID-19 model by placing these COVID-19-challenged index hamsters and naïve hamsters into closed system units, each comprising two different cages separated by a polyvinyl chloride air porous partition with unidirectional airflow within the isolator (Chan & Yuen, 2020). The study focused on the effect of placing masks between cages. They then acquired the clinical score, viral load, histopathology and expression of viral nucleocapsid antigen. The results showed reduction of the droplet transmission of COVID-19 in the hamster model by using the surgical masks (Chan et al., 2019).

Figure 4 schematically illustrates the scenario of mask wearing and social distancing at 1.8 m (6 feet). As depicted in Figures 1-4, accordingly, wearing of masks is essential at all times in a public place, even with social distancing (Cava et al., 2005; MacIntyre et al., 2009).

## 5 | THE PROPER USE AND REUSE OF MASKS

It is essential to wear masks correctly in order to effectively prevent epidemic diseases. 'Even the best respirator or surgical mask will do little to protect a person who uses it incorrectly', said John C. Bailar,

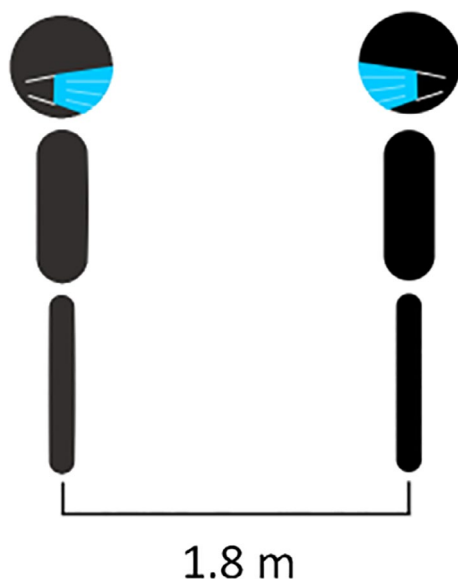


FIGURE 4 Social distancing with masks

professor emeritus, University of Chicago (National Academies of Sciences, 2006). Surgical masks and respirators like N95 s are designed for only single use, because they work by trapping harmful particles inside the mesh of fibres of which they are made (National Academies of Sciences, 2006).

Reuse of the disposable filtering respirators may be needed during times of shortage to ensure continued availability, though there has been no any approved method for decontamination. CDC has provided guidelines about several potential methods to decontaminate disposable filtering respirators, such as ultraviolet germicidal irradiation, vaporous hydrogen peroxide and moist heat (Center for Disease Control & Prevention, 2020).

The current data on the effectiveness of ultraviolet germicidal irradiation (UVGI) on N95 s decontamination shows a single cycle of UVGI with UV-C light being able to decontaminate mask surfaces that have been exposed to virus for both appearance and performance (Hearn et al., 2020). The level of decontamination is determined by cumulative UV (Hearn et al., 2020).

Vaporized hydrogen peroxide ( $H_2O_2$ ) can remove infectious pathogens without affecting mask's function, fit or physical appearance. No  $H_2O_2$  has been tested after 3 h (Cheng et al., 2019). Sodium hypochlorite, ethanol and isopropyl alcohol are not recommended (Cheng et al., 2019; O'Hearn et al., 2020).

Moist heat incubation (MHI), also called pasteurization, is using low temperature to disinfect masks in a humidity environment. The heating cycle of the method (45–55°C) does not reach temperatures known to affect filtration performance (Bergman et al., 2010; Viscusi et al., 2009). In the temperature range of 38–60°C, surface heating can rapidly reduce the viability of viruses (Chan et al., ). When the temperature is higher than 60°C, it can directly kill bacteria and viruses ([https://www.who.int/water\\_sanitation\\_health/dwq/Boiling\\_water\\_01\\_15.pdf](https://www.who.int/water_sanitation_health/dwq/Boiling_water_01_15.pdf))

Disinfection may be able to extend the using time of respirators but if the shape or fabric structure change, this respirator should not be used again. Furthermore, once the mask is wet, soiled, damaged or difficult to breathe during wearing, it should be removed and discarded. Hand-touching of masks should be avoided for possible contamination. If need to touch or adjust their masks, hand hygiene must be immediately followed (Szarpak et al., 2020). Cotton masks, which can be reused by washing, also need to be careful, since the virus may survive on the mask surfaces. Improper reuse of disposable cloth masks may increase the risk of infection (Centers for Disease Control, 2020).

## 6 | SUMMARY

The current research results have shown that COVID-19 is mainly transmitted via droplets in the air. There is a potential risk of airborne transmission in an indoor environment with poor ventilation. The distance of droplet transmission can extend up to 4 m. Based on this data, the recommended social distancing range of 1–2 m (CDC, 2020; WHO, 2020) may not necessarily guarantee the epidemic



prevention. Therefore, wearing mask in public is essential as its effectiveness has already been well established by the current studies. For exhalation isolation, both surgical and N95 masks are shown to be effective in reducing the spread of respiratory diseases, but the former is more accessible and comfortable to wear compared to the latter. For inhalation protection, air filtering respirators such as N95 masks can filtrate contaminants, bacteria and other matters from reaching nose and mouth, and are more efficient in virus penetration inhibition than surgical masks.

Three major filtration mechanisms are identified, namely, interception, inertial impaction and diffusion. While interception takes place for nearby particles, inertial impaction is mainly dominated by some large particles. Diffusion mechanism primarily applies to small particles with diameters around 0.1  $\mu\text{m}$ . A mask design needs to consider all these mechanisms in order to increase the filtration capacity for all particle sizes. As a result, the air filtering respirators are designed to prevent both airborne transmission and the droplets, and highly recommended for the indoor area especially in the high-risk environment. Based on these studies, all people, regardless of physical conditions and professions, should wear masks at all times in prevention of COVID-19. In this regard, inhalation protection via masks is particularly important in order to reduce the transmission of viruses that are potentially carried by droplets and aerosols. The mask requirement has already been proved to be effective, and recently mandated in all states of the United States (Does Your State Have a Mask Mandate Due to Coronavirus?). Considering limited resources in some regions, the home-made masks are shown to have comparable filtration efficiencies compared to the medical masks. A conclusion can be reached based on the current studies: correctly wearing masks of all kinds, despite their different designs, functions and effectiveness, will to a large degree reduce the overall risks of COVID-19 infection and enhance general protection from coronavirus.

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